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SAND2003-0362

Unlimited Release

Printed February 2003

Innovative Business Cases For Energy Storage In a Restructured Electricity Marketplace

Study for the DOE Energy Storage Systems Program

Paul C. Butler, Joe Iannucci, and Jim Eyer

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Innovative Business Cases For Energy Storage In a Restructured Electricity Marketplace

A Study for the DOE Energy Storage Systems Program

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Abstract

This report describes the second phase of a project entitled *Innovative Business Cases for Energy Storage in a Restructured Electricity Marketplace*. During part one of the effort, nine “Stretch Scenarios” were identified. They represented innovative and potentially significant uses of electric energy storage. Based on their potential to significantly impact the overall energy marketplace, the five most compelling scenarios were identified. From these scenarios, five specific “Storage Market Opportunities” (SMOs) were chosen for an in-depth evaluation in this phase. The authors conclude that some combination of the Power Cost Volatility and the T&D Benefits SMOs would be the most compelling for further investigation. Specifically, a combination of benefits (energy, capacity, power quality and reliability enhancement) achievable using energy storage systems for high value T&D applications, in regions with high power cost volatility, makes storage very competitive for about 24 GW and 120 GWh during the years of 2001 and 2010.

Acknowledgement

The authors wish to acknowledge the U.S. Department of Energy, Energy Storage Systems Program for the support of this work. We also gratefully acknowledge the review of this report by John Boyes and Nancy Clark. Finally, we are indebted to Imelda Francis for the technical editing of this report.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

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Acronyms and Abbreviations

| | |
|--------|-------------------------------------------------|
| C&I | commercial and industrial |
| CHP | Combined Heat and Power |
| DP | distributed power |
| DOE | Department Of Energy |
| DOBs | dynamic operating benefits |
| DUA | Distributed Utility Associates |
| ESCOs | energy service companies |
| ESS | Energy Storage Systems |
| FERC | Federal Energy Regulatory Commission |
| I^2R | current squared times resistance (equals power) |
| LLC | Limited Liability Company |
| PJM | Pennsylvania, New Jersey, Maryland |
| PQ | power quality |
| SMO | Storage Market Opportunity |
| T&D | transmission and distribution |
| UL | Underwriter's Laboratory |
| UPS | uninterruptible power supply |
| VARs | reactive power |

Executive Summary

Goal and Scope

This report describes the second phase of the project entitled *Innovative Business Cases for Energy Storage in a Restructured Electricity Marketplace*. During part one of the effort, nine “Stretch Scenarios” were identified. They represented innovative and potentially significant uses of electric energy storage, without regard to financial or institutional hurdles.¹ Based on their potential to significantly impact the overall energy marketplace, the five most compelling scenarios were identified. From these scenarios, five specific “Storage Market Opportunities” (SMOs) were defined in broad terms.

The primary objective for this phase of the project was to use an auditable process to select the most promising of the five SMOs for more in-depth evaluation. The process used is illustrated in Figure ES-1.

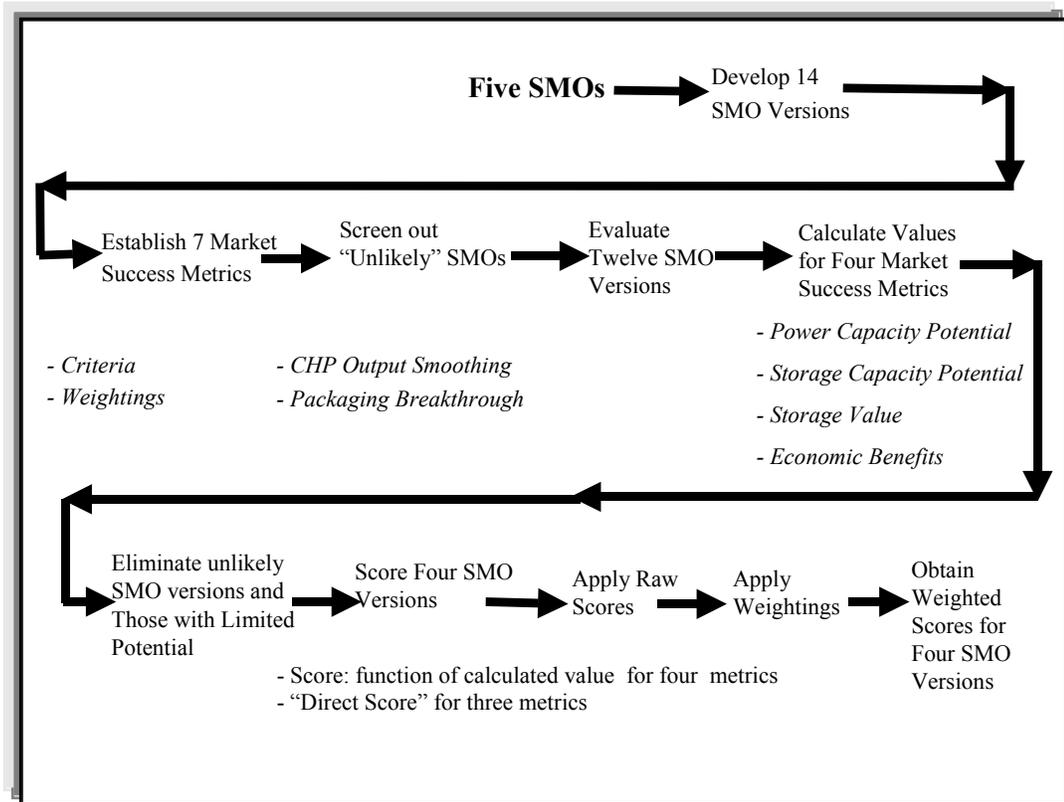


Figure ES-1. SMO Evaluation Process

First, seven Market Success Metrics were defined and their relative importance was weighted. From the five SMOs identified in the previous study, fourteen possible versions of the SMOs were developed for this study. Rough values were calculated for the metrics for each of the SMO versions. Based on those values, the least plausible SMOs were screened out.

Then, raw scores were assigned for each of the success metrics, to which weightings were applied. A weighted score was calculated for each Market Success Metric, for each SMO version scored. These metric-specific weighted scores were summed to calculate the SMO version-specific total weighted score.

Results

Ultimately, four SMO versions were scored. Weighted scores – indicating relative merits of each storage market opportunity scored – are shown in Table ES-1, below.

The SMO version with the highest score (60) was the one with high value for utility transmission and distribution (T&D) capacity (\$90/kW-yr) and volatile on-peak energy price (25¢/kWh) for the 200 hours of the year when electric energy has the highest price. A second version of that SMO was characterized by a lower energy price of 10¢/kWh (for the same 200 hours of the year). That SMO version’s score was 49.

The second highest score (59) applies to the SMO version characterized by an electric utility customer using storage to avoid demand charges of \$60/kW-yr and on-peak energy charges of 10¢/kWh for 650 hours per year.

Table ES-1. Final Scores for Top Four Storage Market Opportunities

| Storage Market Opportunity Version | Total Sum of Weighted Scores |
|----------------------------------------------------------------------------------------------------------------|---------------------------------------|
| Utility: Power Cost "Super Volatility" (60¢/kWh energy for 100 hours/yr plus 15¢/kWh energy for 100 hours/yr). | 49 |
| Customer: Electricity Bill Minimization (10¢/kWh energy, & \$60/kW-yr demand charge, 650 hours per year). | 59 |
| Utility: High T&D Benefits (\$90/kW-yr) & Modest Power Cost Volatility (10¢/kWh), 200 hours per year. | 49 |
| Utility: High T&D Benefits (\$90/kW-yr) & High Power Cost Volatility (25¢/kWh), 200 hours per year. | 60 |

If electric energy prices are “super volatile” (averaging 60¢/kWh during the utility’s 100 most expensive on-peak hours, and 15¢/kWh for the next 100 most expensive hours of the year), and if storage is used by utilities to serve 200 hours per year of on-peak energy consumption, the score is 49.

Conclusions

The authors concluded that a *combination* of benefits (energy, capacity, and power quality/reliability enhancement) is achievable if electric utilities use energy storage systems for high value T&D applications. In regions with high power cost volatility, energy storage is very competitive for up to 24 GW and 120 GWh during the years 2001 to 2010. Such storage would be worth a total of \$26B in gross economic benefits in the U.S., which is equivalent to \$218/kWh (e.g., constant-year benefits for 2001).

The authors recommend that phase three of this study involve development of a business plan to exploit the potential for energy storage capacity used for high value T&D applications in regions with high power cost volatility.

The focus of phase three would be: 1) the market planning portion of the business planning effort, and 2) technological requirements for storage if it is to serve applications that are a combination of the High T&D Benefits and the High Power Cost Volatility SMOs.

1. Introduction

The U.S. Department of Energy (DOE), through its Energy Storage Systems (ESS) Program at Sandia National Laboratories, contracted Distributed Utility Associates (DUA) to examine the benefits of energy storage in a deregulated and partially deregulated electric utility environment. The first phase of this work included a study entitled *Energy Storage Concepts for a Restructured Electric Utility Industry*¹, which attempted to go “outside the box” by assuming several difficult situations for the use of energy storage in utility applications. The assumptions that were made allowed for the exploration of a full range of potential storage applications and described electrical systems that took maximum advantage of storage. The hope was that this work would encourage storage developers and potential users to examine more closely near-term applications of energy storage technologies, expedite pathways to the longer-term applications outlined in the report, and accelerate the market development of the technologies. It was clear, however, that additional work was required to quantify these opportunities.

The follow-on study presented here, *Innovative Business Cases for Energy Storage in a Restructured Electricity Marketplace*, undertakes the refinement of the scenarios outlined in the previous study. The five scenarios that showed the most promise for making a substantial impact on the electricity delivery system were chosen for an in-depth evaluation.

The scenarios identified in the earlier work represented new and potentially significant uses of electric energy storage. The five most compelling of these are identified below:

- Power Cost Volatility
- Transmission and Distribution Benefits
- Enhanced Environmental Externalities
- Combined Heat and Power Output Smoothing
- Storage System Packaging Breakthroughs

DUA took these five scenarios and defined five specific storage market opportunities (SMOs) for further evaluation in this study.

Project Goal and Scope

The goal of this project was to create a process for characterizing the five SMOs, use the process to estimate the potential significance of each, and then identify the most promising SMO versions for further investigation.

Seven “Market Success Metrics” were assumed to be key criteria affecting the prospects for significantly increased use of energy storage. These were used to evaluate the prospects for SMOs. The Market Success Metrics are described in detail later this report.

The storage devices of interest in this study included:

- ones that use either electrochemical or mechanical technologies.
- ones that can be part of a distributed power (DP) resource for use by electric utilities, utility customers, or other participants in the greater electricity marketplace in the U.S.—henceforth referred to as the electricity marketplace.

The study did not address thermal energy storage, including that for cooling, nor did it address energy storage for transportation applications, though some storage technology/system cost and performance improvements could be driven by transportation-related R&D.

This report documents the process used to: 1) characterize the SMOs in detail, 2) estimate the potential significance of each SMO using the market success metrics, and 3) identify the most promising SMO to investigate further. The process was used as a framework to evaluate and quantify the potential for increased use of cost-effective energy storage and to provide projections of economic benefits during the years 2001 to 2010, given a restructured, competitive electricity marketplace.

2. SMO Quantitative Evaluation Overview: Method and Criteria

The process and criteria used in the qualitative and quantitative evaluations to identify the most promising SMOs are shown in Figure 1. Details are introduced in this section and are described in greater detail later in this report.

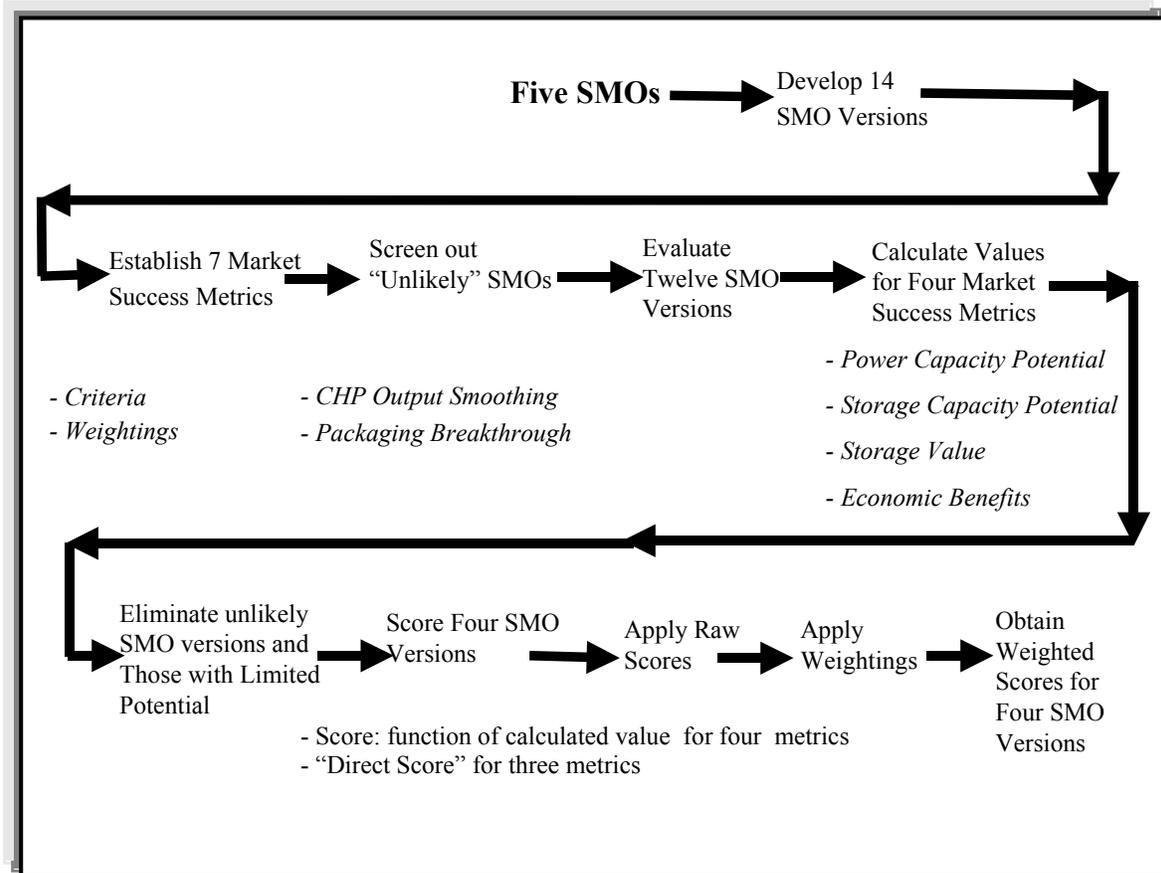


Figure 1. SMO Evaluation Process

Establish Market Success Metrics

Before developing the SMOs, the authors established the criteria for evaluating the relative merits of SMOs. For the study, seven such criteria were defined, and they were called Market Success Metrics. Further, to reflect the relative importance of each market success metric, they were weighted. The seven market success metrics are described in detail in Section 4.

Define SMO Versions

From the five SMOs chosen for this study, 14 SMO versions were developed. The five SMOs and the associated 14 SMO versions are summarized in Table 1. Two of the initial five SMOs were eliminated early in this study using mostly qualitative criteria. During

the preliminary qualitative evaluation, the Combined Heat and Power (CHP) Output Smoothing and Storage System Packaging Breakthrough SMOs were determined not to be viable because of limited market potential and/or applications.

| Table 1. Summary of SMOs and SMO Versions | | | |
|--------------------------------------------------|-----------------------------------------------------------------------------|--------------------|--------|
| 1 | Power Cost Volatility | Calculated Metrics | Scored |
| 1.1 | Utility: Super volatile power cost | Y | N |
| 1.1.a* | Utility: Super volatile power cost, w/mid-peak storage | Y | Y |
| 1.1.b | Utility: Moderate power cost volatility | Y | N |
| 1.1.c | Utility: High volatility power cost | Y | N |
| 1.1d | Utility: PJM 2000 on-peak power cost | Y | N |
| 1.2 | Utility: High volatility power cost, plus average T&D value | Y | N |
| 1.3 | Utility: High volatility power cost, plus PQ benefits | Y | N |
| 1.4* | Customer: Moderate power cost volatility, plus PQ demand reduction benefits | Y | Y |
| 2 | Transmission & Distribution | | |
| 2.1 | Utility: T&D value, modest power cost volatility | Y | N |
| 2.2* | Utility: T&D value, modest power cost volatility | Y | Y |
| 2.3* | Utility: T&D value, high power cost volatility | Y | Y |
| 3 | Enhanced Environmental Externalities | Y | N |
| 4 | Combined Heat and Power Output Smoothing —no metrics, not scored | N | N |
| 5 | Storage System Packaging Breakthroughs —no metrics, not scored | N | N |
| * Most promising SMO Versions | | | |

The twelve remaining SMO versions included eight versions of the Power Cost Volatility SMO, three versions of the T&D Benefits SMO including a “combination” version (High Power Cost Volatility and High T&D Benefits), and one version of the Enhanced Environmental Externalities SMO. Details of SMOs 1-3 are shown in Appendix A.

Calculate Values for Four of Seven Market Success Metrics

The overall technical market potential for energy storage was estimated before the metric values could be calculated. The maximum technical market potential was then reduced based on known technical constraints to determine SMO-specific technical market potential estimates. These technical market potentials were the estimated quantities of energy storage equipment that could actually be used for a SMO given any technical constraints such as the maximum amount of electric load in a given region.

Another step required before scoring was to calculate *values* for four of the seven market success metrics for each SMO version that passed the initial screening.

Metrics for which values were calculated were:

- 1) Power Output Capacity Potential, total over 10 years (gigawatts, GW)
- 2) Storage Capacity Potential, total over 10 years (gigawatt-hours, GWh)
- 3) Storage Value (\$/kW “benefit” per hour of energy storage)
- 4) Economic Benefits, 10-Year (Storage Capacity Potential * Storage Value)

Calculation details are shown and described in Appendix A, Table A-2 – SMO Benefit and Market Potential.

Eliminate SMO Versions with Limited Potential or for which Necessary Market Conditions are Unlikely

Based on the values calculated for the four Market Success Metrics, and on the authors’ judgment about whether necessary market conditions would exist, the least promising SMO versions were eliminated. To summarize, if a given SMO version appeared to yield low net benefits and/or if the market potential for the SMO version was small or unlikely, it was eliminated. Four SMO versions remained for further scoring after this step.

Scoring: Four ‘Most Promising’ SMO Versions

The next step in the process was to apply a raw score to each of the seven Market Success Metrics for those four SMOs. For four of the metrics: Power Output, Storage Capacity, Storage Value, and Economic Benefits—the raw score (0 to 1) applied was a function of the metric’s calculated value. For the three other metrics—Environmental Benefits, Technology Innovation Opportunity, and Scenario Likelihood, the raw score (0 to 1) was applied directly. Finally, market success metric weightings were applied to the raw scores. The result was a total weighted score indicating the relative merits of each of the four SMOs scored.

3. Storage Market Opportunities

Generic Facets

This section describes generic, overarching concepts, topics, and market forces affecting the prospects for electricity storage and the conditions necessary for commercial success. The SMO-specific sections refer to these generic, overarching topics and provide the SMO-specific details.

When evaluating the benefits of SMOs – benefits that would drive an increased use of storage – it is important to consider two perspectives: that of energy end-users and that of electric utilities. It is likely that third parties, especially energy service companies (ESCOs), may also play an important role. However, the authors assume that third party participation would ultimately involve some type of “benefits sharing;” third parties would, in essence, make a profit by sharing benefits with utilities and/or end-users.

Energy End-user Perspective on Energy Storage

In summary, the key criteria used by energy end-users to decide whether to purchase or operate an electric energy storage system include:

- Overall energy cost/bill optimization
 - energy purchases
 - electric utility demand charges
 - necessary electric supply reliability
 - necessary power quality (PQ)
- Up-front capital equipment cost (financial risk and priorities for capital)
- Green energy (possible emission offsets or energy price premiums)
- “Novelty” approach to grid independence

Generically, customers will use the least cost means to accomplish what is needed (for a given level of electricity capability). In this case, the capability would include getting the quantity of electricity needed, when it is needed, and with the required quality. To an increasing extent, end-users also have an interest in environmental externality issues.

With respect to electric energy bills, there are several considerations. One is the cost for electric energy, based on energy price per kWh. Another is the fact that end-users often must pay what is essentially a use fee to utilities for electricity delivery equipment—often called demand charges. Another is an electricity service fee that may be borne by customers, even if specific customers do not benefit directly, which relates to the utility’s need to provide power reliably. Finally, utilities must provide power that is of sufficient quality. All customers must pay their share of the cost of reliability even if it does not help them directly.

In many cases, even if an energy storage system provides superior benefits, energy end-users may still be reluctant to install a storage system if it requires a significant capital outlay or if break-even is achieved more than three to five years out. Often, for all but the largest companies, making an investment that “loses” for five years and “gains” for the subsequent ten to twenty years is considered to be an inferior option as compared to the returns achievable if capital was put to other uses (opportunity cost). Beyond opportunity cost and “lost” near term returns, there is an inherent financial risk associated with investing now to achieve later returns.

In a few cases, customers may install off-grid electricity systems as their primary power source because it allows independence from the utility company. If so, energy storage may be an important part of the system, especially if intermittent generation sources are used.

Electric Utility Perspective on Energy Storage

The most notable considerations used by electric utilities to evaluate the merits of electric energy storage systems are:

- Electric Energy Cost (\$/kWh)
- Transmission and Distribution (T&D) Capacity Cost (\$/kW-yr)
 - taking advantage of the on-peak and off-peak differential
 - reducing the use of the least efficient and most polluting generation (“peakers”)
 - using more constant, efficient, and the least polluting (“baseload”) generation plants
 - reducing T&D, or “I squared R” (I^2R), energy losses
- Improved Service: PQ and/or Reliability
- Up-front Capital Equipment Cost (financial risk and priorities for capital)
- Improved Utilization of Existing Utility Assets (\$/kW-yr)
- Dynamic Operating Benefits and Ancillary Services
- Reduced Environmental Impact
 - incremental plant (getting a permit)
 - fleet (offsets)
 - storage enables more fuel efficient/less polluting operation of an electric generation fleet

It is important to note an implicit assumption is that utilities are allowed to have systems in place that participate in generation, transmission and distribution transactions.

Electric energy cost (\$/kWh) is the cost to make or buy electric energy. Utilities either make electricity or purchase it. Storage allows utilities to take advantage of the difference between electricity cost during on-peak times and that during off-peak hours. Furthermore, if storage is located near the load, then I^2R energy losses associated with

transmission and distribution of energy may be reduced, thus modestly reducing fuel use for generation.

T&D capacity costs are those borne by utilities to install, own, and operate transmission and distribution wires, transformers and other equipment. These T&D assets are depreciated over thirty or more years. Once utilities invest in capital projects such as transmission and distribution, these costs are reflected in the carrying charges, or fixed charge rate of borrowing to cover those investments. The fixed charge rate includes factors such as depreciation, and typically is in the range of eight to twelve percent per year. Thus a transmission and distribution investment of \$300/kW could have an annual cost to the utility of roughly \$30/kW/year. That is, it costs \$30 per year to provide capacity to serve 1 kW of load. Transmission capacity is required to move energy from power plants to various areas and regions all over the country, and distribution capacity is needed to deliver electric energy from the transmission system to customers. Most costs incurred are for interest and dividends paid for capital used to finance the purchase of wires, transformers, and other equipment.

Also important to utilities – though not evaluated here – are two facets of generation, transmission, and distribution capacity asset ownership: 1) up-front capital equipment cost (that drives financial risk associated with a given “investment” option), and 2) improved utilization of utility assets e.g., allowing for additional profitable delivery of electricity via a specific distribution line during a given year.

Depending on how it is used, energy storage can provide power quality and electric service reliability improvements. Specifically, depending on location and duty cycles, energy storage can provide voltage support in areas where voltage “sags” occur, or can generate reactive power (VARs) where low power factor is a problem. Storage can also provide power during outages, to carry loads alone or in conjunction with back-up generation systems. High quality/reliability power is becoming a compelling value-added service offered by utilities.

Energy storage may enable more fuel efficient, less polluting and generally more optimal operation of an electric generation fleet. Such “dynamic operating benefits” (DOBs) associated with energy storage use affect both the cost of, and environmental effects from, a generation fleet.

DOBs include more constant operation of the most efficient plants (i.e., less “ramping”), fewer start-ups and shutdowns of peaking power plants, and reduced operation of power plants to provide reserve margin. DOBs affect such things as generation cost, fuel efficiency, wear and tear, thermal cycling, and pollution. In addition to DOBs, the Federal Energy Regulatory Commission (FERC) specifies “ancillary services” that may also apply, such as transmission voltage stabilization. Dynamic operating benefits and ancillary services were not considered explicitly for this evaluation because they were assumed to be reflected in unit energy cost.

Reduced environmental impact due to energy storage use was also not considered explicitly for this study, except when evaluating the possible financial benefits associated with “enhanced” environmental externalities.

One key benefit associated with distributed power is that it may allow utilities to defer or avoid transmission and/or distribution system upgrades. But, unless electric power resources are located close to loads (i.e., within less than one mile), transmission and distribution related benefits do not accrue. Access to the utility transmission system may also be an issue. Many utility systems are expected to become more congested over the next ten years.

If storage is used in conjunction with on-site generation, then fuel access may also be affected by location, whether delivered by trucks/tankers or pipes.

This evaluation took into account the significant synergies between the five SMOs and other energy storage applications. As an example of important synergies, a battery storage system installed for the Power Cost Volatility SMO can be considered for additional applications. That same system could provide benefits associated with the Enhanced Environmental Externalities, Transmission and Distribution Benefits, and Combined Heat and Power Output Smoothing SMOs. It could also be used to address more common applications for energy storage: power quality, “carryover” electricity needed while on-site generation starts up during grid outages, and as an uninterruptible power supply (UPS) providing enhanced electric service reliability.

SMOs and SMO ‘Versions’ Evaluated as Candidates for Scoring

Storage Market Opportunity 1: Power Cost Volatility

Description

Energy storage can be used to take advantage of differences in cost or price between:

- 1) Electric energy available during periods when demand is low, and
- 2) Electric energy available during peak demand periods.

Utilities and energy providers could use low cost “off-peak” electricity (generated by the utility or purchased in the wholesale marketplace) for resale when electricity prices are higher. In fact, utilities have been doing this for many years, primarily using pumped hydroelectric systems. Similarly, utility customers could purchase and store low priced retail energy during off-peak periods, for discharge to avoid purchasing higher priced energy during peak demand periods.

Consider the data in Table 2 (more detail is shown in Appendix B), which contain market-based energy prices for the central portion of the Eastern U.S. (in the Pennsylvania, New Jersey, Maryland (PJM) Electric Reliability Council Region). Based on these prices, \$63 per year of net value could be realized for each kilowatt of storage

capacity installed if the storage plant can provide energy for just 200 hours per year. For the entire \$63/kW-yr to be realized, the storage system must actually serve all energy needs, during the 200 hours of the year when the energy price was highest. For the most part, these hours were not contiguous; they were the 200 hours during the year in which the utility peak demand occurs. For most utilities, peak demand occurs mid-day during summer weekdays. Also, several of the top 200 hours may indeed occur on the same day of the year if that day is extraordinary (e.g., an especially hot day).

Table 2. Example: Value of Stored Electricity in the PJM Region

| Load Duration Hours | | | Energy Value | | Charging Cost | | | Net Value | |
|---------------------|-----------|----------------|------------------------------|--------------------------------|-------------------------------|--------------------------------|------------------------------|-------------------|-----------------------|
| First Hour | Last Hour | Hours Per Year | Average Energy Price (¢/kWh) | Annual Energy Value (\$/kW-yr) | Charging Energy Price (¢/kWh) | Charging Energy Cost** (¢/kWh) | Annual Charging Cost (\$/kW) | Annual (\$/kW-yr) | Cumulative (\$/kW-yr) |
| 1 | 43 | 43 | 93.0 | 40.0 | 3.0 | 4.6 | 2.0 | 38.0 | 38.0 |
| 44 | 94 | 51 | 40.0 | 20.4 | 2.0 | 3.1 | 1.6 | 18.8 | 56.8 |
| 95 | 200 | 106 | 9.0 | 9.5 | 2.0 | 3.1 | 3.3 | 6.3 | 63.1 |
| 201 | 1,000 | 800 | 5.0 | 40.0 | 2.0 | 3.1 | 24.6 | 15.4 | 78.5 |
| 1,001 | 2,000 | 1,000 | 2.8 | 28.0 | 1.5 | 2.3 | 23.1 | 4.9 | 83.4 |

**Round Trip Efficiency 65%

It is very important to note that this incremental/energy cost reduction does not account for the cost of the storage system itself. For a given energy storage project to be cost-effective, accrued benefits (because low-cost energy was used to provide higher value energy) must cover carrying charges for the capital plant (primarily equipment, engineering, installation costs, and taxes) plus an attractive return on capital invested in that system.

Power Cost Volatility SMO Versions

Eight versions of the Power Cost Volatility SMO were considered.

Version 1.1. Utility: Super Volatile Power Cost.

Version 1.1.a. Utility: Super Volatile Power Cost, w/Mid-Peak storage discharge.

Version 1.1.b. Utility: Moderate Power Cost Volatility.

Version 1.1.c. Utility: High Volatility Power Cost.

Version 1.1.d. Utility: PJM 2000 on-Peak Power Cost.

Version 1.2. Utility: High Volatility Power Cost, Plus Average T&D Value.

Version 1.3. Utility: High Volatility Power Cost, Plus PQ Benefits.

Version 1.4. Customer: Moderate Power Cost Volatility, plus PQ & Demand Reduction Benefits.

Observations

Plant scale was a very important criterion when assessing the potential for this SMO. Large scale “merchant” plants do not seem viable, per se, as discussed in Section 4 under the Storage Capacity Potential Market Success metric.

Another key criterion affecting the viability of storage systems was the type of storage system owner i.e., utility or utility customer. For customers, the overall cost per kW tended to be onerous. Furthermore, for storage to be viable for customers, time-of-use electricity rates or other means by which to purchase inexpensive energy for charging the storage system must be available and grid interconnection must be allowed and must be reasonable.

Distribution utilities owning storage plants would probably not incur the same interconnection costs as would electricity end users. They also probably have means to take advantage of energy price differentials based on internal utility cost to generate, and/or the wholesale price for electricity during periods of low demand. However, in many cases utilities may not be allowed to own a storage facility. If utilities are allowed to own these facilities, they may be able to share the benefits with customers.

Even if energy storage use is not competitive for the Power Cost Volatility SMO, synergies with the Transmission and Distribution Benefits SMO and possibly the Environmental Benefits SMO can yield total benefits that may be attractive.

SMO 1: Conclusions

This SMO was selected for further analysis as described in more detail in Section 5.

Storage Market Opportunity 2: Transmission and Distribution Benefits

Description

Energy storage, located at the physical site where the energy will be used, can provide significant financial value related to electricity transmission and distribution (T&D). The most important reason to use storage to support the T&D system is the “capacity benefit” (\$/kW) provided. This accrues if on-site energy storage is located where utility transmission and/or distribution systems are and will soon become overloaded or constrained. If so, storage can provide modest to significant financial benefits associated with deferred or avoided transmission and/or distribution equipment upgrades.

Another important, and in some cases overriding, T&D benefit was enhanced service reliability and/or power quality for critical loads.

Avoided “I squared R” resistive losses (net of on-peak versus off-peak of ~3%) are a less significant potential benefit. They accrue to the extent that locating storage at or near loads will reduce current flow through transmission or distribution systems on-peak.

For utilities that own or pay to use others’ T&D equipment, capacity benefits and avoided I²R losses result in lower overall cost to provide electric service to customers.

For utility customers to realize T&D capacity benefits, electric service prices must reflect actual benefits or customers cannot internalize or share those benefits. Electric service prices reflecting T&D benefits may come in one or more of the following forms:

- 1) Demand charges (\$/kW of power draw during times when demand is high), perhaps even distribution circuit-specific charges,
- 2) Energy time-of-use charges, and
- 3) Interruptible rates requiring customers to turn off loads connected to the grid when requested, for a given number of hours, on a specified number of occasions per year—storage must “pick-up” this load on-site when power delivery is actually interrupted.

T&D Benefits SMO Versions

Three versions of the T&D Benefits SMO were considered.

Version 2.1. Top 50% T&D Value, 10¢/kWh wholesale.

Version 2.2. Top 10% T&D Value, 10¢/kWh wholesale.

Version 2.3. A combination of SMO versions 1.1.a. & 2.2 --“Top 10% T&D Value plus Super Volatile w/Mid-Peak 1.1.a.

Observations

Generally, for T&D benefits (except PQ improvement) to accrue, storage capacity (kWh) per kW of discharge capacity will have to be at least one kWh/kW and may have to be as much as four kWh/kW or more. The driver is the duration of T&D capacity constraints being addressed with the storage plant—this is without regard to any power supply shortages. It is reasonable to believe that this may be as much as six to eight hours in some cases.

It is important to note that capacity constraints typically only occur for 50 to 200 hours of the year, unless the T&D system is completely inadequate. The implication is that a large storage capacity (per kW) may not be used often enough for the project to be financially viable based on T&D capacity benefits alone.

However, if T&D reliability and benefits associated with two other SMOs, Power Cost Volatility and Enhanced Environmental Externalities can also be captured, then total benefits may be quite attractive for a significant number of cases. It must be noted that

both the Power Cost Volatility SMO and the Enhanced Environmental Externalities SMO require relatively large energy storage capacity per kW of system power output.

SMO 2: Conclusions

This SMO was selected for further analysis as described in more detail in Section 5.

Storage Market Opportunity 3: Enhanced Environmental Externalities

Description

It is likely that key environmental effects associated with electricity production include several types of air emissions: NO_x, SO_x, CO, and CO₂, particulate matter, and possibly methane, mostly produced as by-products of combustion-based generation. If so, the following manifestations could result:

- 1) Some types of generation (primarily combustion-based) and/or specific power plants will not be allowed at all or their operation hours may be limited, based primarily on air emissions in general, and/or localized environmental effects.
- 2) Charges, possibly significant, may be assessed for one or more of the following criteria:
 - a. specific types of electric generation,
 - b. specific generation plants,
 - c. specific jurisdictions,
 - d. specific air emission type(s), and
 - e. pollution during specific times.
- 3) A marketplace that enables trading of emission “offsets.”

Any of the above could have a modest to significant impact on wholesale and retail prices for electricity, especially incremental electricity production to serve peak demand because these “peaking” power plants are usually: 1) combustion-based, 2) the least efficient/most expensive, and 3) the most polluting.

With respect to reducing pollution from generation using energy storage, depending on the number of hours per day that the energy system is discharged and the number of days per year that the energy storage was used, energy storage could provide the following benefits.

- Allow utilities to reduce or avoid use of least efficient and most polluting peaking generation.
- Enable more efficient operation of baseload combustion-based generation facilities – by allowing more constant output at or near rated output – for less pollution per kWh generated.

- Reduce T&D I²R losses – less fuel is used (and thus less pollution is produced) per kWh delivered, especially during periods of peak demand for electricity when T&D I²R losses are greatest.
- Possibly affect where and when pollution occurs in a desirable way (e.g., pollution could be shifted to areas that are not air quality “non-attainment” regions or utilities might “time-shift” pollution to less critical times of the day).

Another way that storage may be used to reduce air emissions is to store energy from clean renewable generation sources with output that is intermittent so that the energy from the renewable generation plant is more reliable, dispatchable and thus more valuable. This can involve renewables that are not connected to the grid or ones that are grid-connected and thus subject to price and market vagaries.

Depending on how much and when energy storage is used to reduce air emissions, this SMO may have important synergies with other SMOs.

- Power Cost Volatility
- Transmission and Distribution Benefits
- Combined Heat and Power Output Smoothing

Observations

Option 1 – Use Cleaner Resources to Charge, Reducing Use of Dirtier Generation During Discharge

For storage to provide a significant reduction in air emissions from generation, energy used for charging must be produced by generation that is significantly “cleaner” than generation producing energy that would be used if the battery did not provide equivalent electricity.

Specifically, generation for charging electricity would have to produce 30 to 40% less air pollution just to overcome the charge-discharge losses of storage. The same applies to financial benefits: the difference between the price of off-peak electricity for charging and the price for electricity use “avoided” when the battery discharges must be at least 30 to 40% to overcome round trip losses.

Even if energy from a storage device results in much less pollution per kWh delivered to the load, to have a significant overall impact on pollution (per kW installed), storage systems would have to provide electricity for a significant number of hours per year. To have a large impact on pollution nationwide or globally, a significant portion of all electric load would have to be served by storage during peak demand periods.

Consider the illustration in Appendix C—storage efficiency was assumed to be 65% for a system that provided 1,000 hours of discharge per year. In the example, NO_x reductions were significant because the most polluting utility resources were used less. However,

due to storage round-trip losses, a lot of low-priced energy was needed to charge the storage plant such that resulting cost reduction was not very significant.

Specifically, the “blend” of on-peak and mid-peak energy cost avoided (7.1¢/kWh) versus off-peak energy cost of 3.5¢/kWh (for charging at 65% efficiency) led to a modest utility energy cost reduction of about \$17/kW-yr given reasonable assumptions.

It bears noting that the results shown in Appendix C are for illustration only, and they are not used elsewhere in the report.

Option 2 – Enabling Off-Grid Renewables

Storage is already an important element of many off-grid PV systems. To date, off-grid systems have generated a very small portion of all energy consumed. However, in developing countries without existing electric utility infrastructure, such off-grid systems may be the only viable option. In many of the same countries, the only available fuels (e.g., Diesel fuel and coal) are quite polluting and in many cases, overuse of local biomass sources result in soot-related pollution.

Option 3 – Enabling Grid-Connected Renewables

Biomass, geothermal and hydroelectric generation tend to be “baseload” resources, so they are not intermittent. They also tend to have high capital plant cost per kW so adding more capital equipment in the form of energy storage may make overall plant cost (per kW installed) too high or financially risky.

It should be noted that energy storage used with these baseload renewables has characteristics and considerations similar to those described in the section of this report covering the Power Cost Volatility SMO and the Combined Heat and Power Output Smoothing SMO.

Because solar generation is relatively expensive (per kW installed) and because solar generation’s output tends to be coincident with peak demand periods, grid interactive solar electric systems are not good candidates for pairing with energy storage.

Wind generation is the most likely candidate for coupling with storage; its output is usually much less coincident with demand for electricity, and the cost per kWh generated is relatively low as is the installed cost (per kW).

One facet related to the Enhanced Environmental Externalities SMO is the fact that without storage there is a technical limit to the amount of wind generation that can be added to the greater electric supply system, perhaps as much as 20% of the peak demand. Because wind generation is intermittent, and because it may not occur when electricity is needed (i.e., during periods when demand for electricity is high), wind generation must be supplemented with “dispatchable” resources that fill-in when both demand for electricity is high and wind generation is low. Central supply systems can either start-up additional resources or “ramp up” operating plants to meet demand, which limits the amount of wind generation that a central supply system can accommodate efficaciously.

Two points should be made with regard to storage: 1) Grid operators can rely on wind-generated electric energy to be available when needed; thus making more wind generation capacity viable technically, and 2) The value of wind-generated electricity is higher if output from the wind generation during periods of low demand can be stored and used during high demand periods when electricity is most valuable.²

For this SMO, the amount of storage that was viable (market size) was mostly a function of several key parameters: 1) cost for energy storage systems (kW and kWh), 2) storage system round-trip efficiency, 3) cost for wind generation (per kWh including capital charges), and 4) price for charging energy and for energy purchases “avoided” during storage discharge. The amount of viable storage was also a function of the value of environmental externalities that may apply.

Readers should note that this storage business opportunity is defined as an extreme case involving an urgent need for clean generation, primarily to reduce the use of coal-burning plants. In such a scenario, wind generation is assumed to supply a large amount of total electricity to the grid. The implications for energy storage are significant.

Consider the extreme case: wind generation supplies all grid energy. Given seasonal and diurnal wind patterns and system demand patterns in the Midwest, West, and Texas, about 500 hours of storage are required if wind generation is to serve all regional load.³ Based on that information, for this study the conservative value of 100 hours was used.

Readers should also note that the scenario evaluated for this study involving the significant use of wind to supply a large amount of energy is much different than situations involving wind generation used in off-grid, self contained “min-grids,” or power systems for small islands. In those situations several hours of storage would provide significant benefit, especially if the wind generation system also has diesel engine generation.

SMO 3 Conclusions

After an initial evaluation, the authors concluded that it was unlikely that actual financial premiums required to make the Enhanced Environmental Externalities SMO viable (i.e., to offset storage system equipment and charging costs) would exist during the study period. Furthermore, the value target for storage cost was quite high. Therefore, the Enhanced Environmental Externalities SMO was not scored.

Storage Market Opportunity 4: Combined Heat and Power Output Smoothing

Description

Ideally, Combined Heat and Power (CHP) electricity generation equipment is operated in a baseload duty cycle to reduce cycling and to maximize asset utilization. Furthermore, most thermal loads served by CHP systems require heat most or all of the year.

Even in some well-designed CHP systems, a discontinuity between heat loads and electricity loads served by a CHP system may occur. The result is that there are times when a) heat is needed, and b) some or most of the electricity generated is not needed. In addition, CHP systems often have a start-up cost (including staffing and effects from thermal stress). Combined Heat and Power systems may also require a significant amount of time between plant start-up and the time when the system can produce heat at the maximum rate.

If a CHP plant does operate when electricity generated exceeds on-site needs, then the options are: 1) “dump” electricity, 2) if possible, sell electricity at a “low” price in real-time, 3) store, and use or sell the energy when electricity is expensive and/or electricity demand is greatest, or 4) operate the CHP system at part load, increasing pollution and fuel use per kWh.

Storage could be an important part of a CHP system. Possible benefits include:

- 1) Increased asset utilization (assuming stored energy yields a net positive value),
- 2) Increased CHP plant annual average fuel efficiency,
- 3) Reduced annual average emissions per kWh produced, and
- 4) Reduced thermal stresses (due to cycling and start-ups) on prime mover equipment.

Observations

Combined Heat and Power together with electric energy storage would be particularly viable in power parks and for large institutional/commercial uses (colleges/universities, prisons, hospitals, hotels, etc.). The Combined Heat and Power Output Smoothing SMO may have important overlaps with the following SMOs:

- Enhanced Environmental Externalities
- Electric Energy Price Volatility
- Transmission and Distribution Benefits

Many CHP units are sized to meet thermal loads. That way, they operate most efficiently, for the greatest possible number of hours per year, to provide the most profitable, cleanest operation possible. In this case, the balance of electricity needed for operations was purchased or generated with another unit.

SMO 4 Conclusions

The Combined Heat and Power Output Smoothing SMO did not seem likely to be viable based primarily on financial criteria. Combined Heat and Power systems have a high cost per kW before adding financial risk associated with the incremental cost of adding

storage. Most cogeneration systems are sized so that most if not all electric output is used directly, to avoid oversizing the (expensive) generation equipment. Furthermore, thermal energy is less valuable (i.e., costs less to replace) than electricity, so CHP systems can usually be designed to provide the greatest electricity-related benefits.

Given those conclusions, the Combined Heat and Power Output Smoothing SMO was not scored.

Storage Market Opportunity 5: Storage System Packaging Breakthroughs

Description

This SMO depends on breakthroughs in materials and/or system design that would lead to a significant increase in sales of storage that would affect the electricity marketplace. As a hypothetical example, consider volume, footprint, and weight of a lead-acid battery system capable of powering the typical home for four hours (e.g., 2 kW/8 kWh). Any or all of those criteria could make batteries unattractive for some or even many residential applications. If the plant footprint or volume was too large, then space could be an issue, especially in smaller homes or high density housing developments. Batteries tend to be heavy—older or multi-story structures may not be able to support the weight.

If a very high energy density storage device with a small volume/footprint is developed, or if storage devices developed could be used as part of a building's infrastructure (e.g., as a wall), then storage systems for "on-site power backup" might be more attractive.

Ultimately, technological breakthroughs boil down to one or more of the following key results:

- 1) Reduced plant size: footprint or volume
- 2) Reduced weight
- 3) Improved "form factor flexibility"
- 4) Improved "safety" and/or reduced health effects
- 5) Reduced "hassle" (e.g., "plug and play," Underwriter's Laboratory (UL) Approved)

Observations

The authors could not identify scenarios under which packaging breakthroughs would result in a significant increase in demand for electricity energy storage. Without a doubt, storage for transportation applications will benefit from packaging breakthroughs, especially those leading to lighter batteries with a more flexible form. Of course, a significant increase of battery use for transportation would also have a significant effect on the electricity infrastructure and marketplace. It may lead to developments that increase the use of storage for stationary applications.

However, cost reduction will drive most new demand for stationary storage systems. The authors acknowledge such recent breakthroughs as “paper batteries;”⁴ these seem more suited for “value-added” applications and do not seem likely to result in a “significant increase in demand for energy storage,” given their modest power and energy output.

SMO 5 Conclusions

The authors could not identify any application for which a significant amount of storage could be used if the storage packaging was “ideal.” Ultimately, it was cost and performance that were most important for utility power applications. (However, the authors note the importance of packaging for other applications, most notably transportation.)

Based on those premises, the Storage System Packaging Breakthroughs SMO was not scored.

4. Market Success Metrics and Market Potential Estimation

The seven market success metrics (MSM) used for scoring were:

- 1) Power Output Capacity Potential (gigawatts, GW)
- 2) Storage Capacity Potential (gigawatt-hours, GWh)
- 3) Storage Value (\$/kW “benefit” per hour of energy storage)
- 4) Economic Benefits Potential (Storage Capacity Potential * Storage Value)
- 5) Environmental Benefits (a score between 0 and 1)
- 6) Technology Innovation Opportunity (a score between 0 and 1)
- 7) Scenario Likelihood (a score between 0 and 1)

Assumptions Used to Calculate Values for Market Success Metrics

The following assumptions were used to calculate values for the first four Market Success Metrics.

Energy Unit Cost/Price

Only off-peak energy was used for charging the energy storage device, and it was assumed to cost 3¢/kWh.

For the “super volatile” version of the Power Cost Volatility SMO (version 1.1.), the cost for electric energy was assumed to be 60¢/kWh for 100 hours per year. Version 1.1.a. adds consideration of benefits associated with storage use given a cost of 15¢/kWh for 200 additional “shoulder hours” per year. Shoulder hours refer to time periods when energy is expensive but not at the highest cost periods.

High volatility cost for electric energy was based on the proposed price cap in California of 25¢/kWh, assumed to prevail for 200 hours per year. Moderate volatility cost for power was assumed to be 15¢/kWh for 200 hours per year.

The Pennsylvania, New Jersey, Maryland (PJM) Limited Liability Company (LLC) version of the Power Cost Volatility SMO was based on actual on-peak price/cost from the summer of 2000 of 35¢/kWh, averaged over 200 hours per year.

Power cost with “modest volatility” was supplied to Commercial/Industrial customers paying 10¢/kWh for on-peak electricity for 650 hours per year (six months, five hours per day, such as 12 p.m. to 5 p.m.).

Value of Power Quality and Reliability

The value of improved power quality and reliability was assumed to be \$10/kW-yr. It was assumed to apply to typical commercial/industrial utility customers, and was a conservative value.

Utility T&D Value Assumptions

Three levels of T&D avoided cost (dollars per kW-year of load served) were assumed for the cost borne by utilities to own and operate T&D systems.

Average \$30/kW-yr (\$20 for T plus \$10 for D)
Top 50 percentile \$50/kW-yr (\$20 for T plus \$30 for D)
Top 10 percentile \$90/kW-yr (\$20 for T plus \$70 for D)

The values were estimated in a recent report commissioned by the Edison Electric Institute, in which the average analyzed cost for T&D was set at \$54/kW-year.⁵ Given that mean value and assuming a log normal distribution of costs, it is estimated that the average cost between the 90th and 100th percentiles is close to \$90/kW-year. This is also consistent with the average cost of T&D as reported on by FERC in Form 1 through 1995.

Customer Demand Charges

Commercial/industrial customers were assumed to be assessed a demand charge. A typical value is a \$10/kW-month charge applied during six summer months, during the hours of 12 P.M. to 5 P.M., for a total charge of \$60/kW of load during the entire year (\$60/kW-yr).

Financial Assumptions

For this study, an annualization factor of 0.12 was used to convert annual values (expressed in units of \$/kW-yr) to total installed cost. To convert an annual value to a total value, the annual value is divided by 0.12. The result was the total value for a given kW of storage plant output capacity. For example, the assumed value for the most expensive utility T&D capacity was \$90/kW-yr. Assuming a fixed charge rate of 0.12, that translates into lifecycle benefits of about $\$90/\text{kW-yr} \div 0.12 = \$750/\text{kW}$.

Market Potential

Technical Market Potential

One facet of a market potential assessment for energy is the overall technical market potential—the amount of energy storage equipment that could actually be used, without regard to cost. At the highest level, one measure of the existing technical limit on energy storage equipment nameplate output capacity (GW) was peak demand in the U.S. for electric power, about 800 GW.

Similarly, the maximum amount of energy storage “reservoir” capacity (distinct from output power capacity) that was plausible in a purely technical sense was the amount needed to meet all demand for all electric energy.

SMO-specific Load ‘In Play’

As a starting point when estimating the technical potential for energy storage it was assumed that energy storage would only be added to meet new load growth. So, annual load growth was the basis for estimating the maximum technical potential load in play.

For most SMOs, only a portion of that maximum technical potential (all electric load and/or energy use) was assumed to be “in play.” That is, a given SMO may not include/apply to the entire market for electricity. Thus the SMO-specific load in play was a portion of the maximum technical potential; the portion being a function of SMO-specific benefits and technical requirements.

Success Saturation Adjustments

Because current demand for energy storage systems (excluding that for electrochemical batteries for transportation applications) was quite low compared to technical market potential, a “success saturation” level was assumed for the Power Output Capacity Potential and Storage Capacity Potential market success metrics.

Conceptually, the success saturation level was the portion of the technical market potential that could actually be served with storage given constraints such as time needed for storage manufacturing scale-up, to develop a storage equipment support industry, and for market acceptance. Rigorous estimation of success saturation values was beyond the scope of this study; they were estimated by the authors using their best judgment, as described below.

When scoring market success metrics, if the value calculated for a metric was equal to or greater than the assumed success saturation level, then the SMO version received a score of one for the given market success metric. For example, the customer SMO version for modest electric energy price volatility, PQ benefits, and for demand charge reduction (SMO version 1.4.) is assumed to apply to 75% of commercial and industrial load and load growth, about 650 GW over ten years. However, a market success saturation level of 50 GW was also assumed. As a result, SMO version 1.4. received the maximum raw score of one for that metric.

In general terms, if energy storage technology was advanced such that it was used for even modest portions of the load in play assumed for this study, then the impact on the energy storage industry would be enormous. For example, for storage market opportunities representing “high value” applications, there may be as much as 24 to 50 GW or more in play. Consider the lower value in that range (24 GW), even a modest portion of that, say 20% or 4.8 GW is arguably substantial given present energy storage system sales.

For each SMO version, the success saturation was assumed to be 50 GW for system power output capacity. The highest number of hours of required energy storage capacity assumed for any of the SMO versions evaluated was six hours. The success saturation level assumed for energy storage capacity was, therefore, 6 hours times 50 GW = 300 GWh for each SMO.

Note: market overlaps between SMOs, if any, were not considered.

MSM # 1–Power Output Capacity Potential

The potential amount of all electric load that could be served by storage systems is referred to as Power Output Capacity Potential. It corresponds to the electric utility “load in play” for a given SMO. Load in play is a portion of all “embedded” electric demand and all growth in demand for electricity, over the period 2001 to 2010. Units are in gigawatts (GW).

Embedded load was assumed to be 800 GW, and 10-year load growth was assumed to be 2.5% per year, or 224 GW.

MSM # 2–Storage Capacity Potential

The Storage Capacity Potential (GWh) needed to serve all load in play is the technical potential for energy storage. For storage systems, this drives the number of battery cells used, supercapacitors needed, the size of the pumped hydroelectric storage reservoir needed, the size of the air storage reservoir needed, or the amount of kinetic energy that must be stored by flywheels.

The number of hours of rated output is SMO-version-specific, based on SMO-specific duty cycles. As shown in Appendix A, typical systems for key SMOs require storage ranging from four to six hours, in many cases the requirement was for 5 hours.

To calculate Storage Capacity Potential (GWh) for a given SMO, the SMO-version-specific hours of storage required per kW of system output was multiplied by the Power Output Capacity Potential, or load in play (GW) for a given SMO version.

As an example, if load in play was 25 GW and a SMO-specific duty cycle requires five hours of storage per kW of storage capacity then five times 25 = 125 GWh of market potential for energy storage.

MSM # 3–Storage Value

This criterion is the economic benefit accruing for each kWh of storage required; values are expressed in units of \$/kWh of storage. Higher values are superior. Storage value provides a strong indication of the cost for energy storage that would be required for financial competitiveness for a given SMO.

Storage value is a function of these criteria whose values are SMO-specific:

- Electric energy cost ($\text{\$/kWh}$)
 - on-peak
 - mid-peak
 - off-peak (for charging)
 - utility unit cost and customer unit price
- Energy storage roundtrip efficiency
- Value of T&D capacity
 - utility avoided cost
 - customer demand charges
- Value of superior reliability and power quality
- Value of “green” power production

MSM # 4–Economic Benefits Potential

This metric is the total financial benefits that accrue if all load in play for a given SMO is served by new storage systems. It is calculated, for a given SMO, by multiplying the Storage Capacity Potential (GWh) times the Storage Value ($\text{\$/kWh}$). Units are measured in billions of dollars.

As an example, if the Storage Value is $\text{\$100/kWh}$, and load in play is 25 GW for a SMO requiring five hours of storage capacity, then the Storage Capacity Potential is 125 GWh and the Economic Benefits Potential is $\text{\$12.5 Billion}$.

MSM # 5–Environmental Benefits

This criterion is the extent to which storage installed under a given SMO leads to reduced air emissions per kWh delivered. Included are considerations for 1) generation system dynamic operating benefits, 2) reduced use of inefficient central “peakers,” 3) reduced use of combustion generation overall, and 4) I²R T&D losses (and thus upstream fuel use) avoided. (T&D losses are typically about 7% - 8% on-peak and can be as low as 4% off-peak. Note that if on-site energy storage is charged at night when losses are 4%, and discharged on-peak when losses “would be” 7%, then the net losses avoided are 3%.)

MSM # 6–Technology Innovation Opportunity

This metric is an indication of the extent to which innovation via R&D is needed to enable a given SMO; it is important when considering potential R&D themes.

MSM # 7–Scenario Likelihood

The likelihood scenario metric indicates the probability that the market conditions assumed as underpinnings of a given SMO will exist.

Market Success Metrics Weightings

The relative significance of each market success metric used for the quantitative evaluation was weighted, with the sum of all weightings being 100. Market success metric weightings used are described below.

Weighting of Market Success Criteria

Market Success Metrics' Weighting Factors are shown in Table 3. The rationale for those weightings is described below.

Table 3. Market Success Metrics' Weighting Factors

| | Market Success Metrics | | | | | | | |
|----------------------|---------------------------------|----------------------------|---------------|-------------------|------------------------|----------------------------------|------------------------|------------------------|
| | Power Output Capacity Potential | Storage Capacity Potential | Storage Value | Economic Benefits | Environmental Benefits | Technical Innovation Opportunity | Likelihood of Scenario | Sum of Weighted Scores |
| Weighting (unitless) | 8 | 4 | 25 | 10 | 13 | 20 | 20 | 100 |

MSM 1–Power Output Capacity Potential (GigaWatts, GW)

Weighting: 8 out of 100

The Power Output Capacity Potential market success metric is one of two criteria used to quantify the importance of storage equipment sales/use. For a given SMO, it is the total rated/nameplate power output capacity of all storage systems associated with load in play.

Given the premise that even a modest amount of load in play considered for all SMO versions is very large when compared to present sales of storage systems, this market success metric is assumed to be relatively less important than most other market success metrics, hence the weight of 8 (of 100).

MSM 2–Storage Capacity Potential (GigaWatt-hours, GWh)

Weighting: 4 out of 100

In addition to the Power Output Capacity Potential (GW) market success metric, an additional indicator of the attractiveness of a given SMO is the total energy storage “reservoir” capacity (GWh) that might be installed. The Storage Capacity Potential market success metric reflects that value.

The weighting for this market success metric (weighting of 4) was assigned based on the premise that it adds 50% to the overall weighting/importance assumed for the Power Output Capacity Potential market success metric (weighting of 8). This was assumed, in part, because many of the most viable applications for energy storage involve the need for power output (kW) for just a few moments at a time (i.e., less than one, perhaps much

less than one kWh of energy storage reservoir capacity is required per kW of power output capacity installed).

As with Power Output Capacity Potential, if energy storage technology is advanced such that it is used for even modest portions of the load in play for any of the SMOs evaluated, the impact on the energy storage industry would be enormous.

MSM 3–Storage Value (\$/kW “benefit” per hour of energy storage capacity)

Weighting: 25 out of 100

The bottom line for any technology is whether it provides economic benefit exceeding those from other prospective options. This is the key criterion that will drive competitiveness and market success of storage technology. This market metric is the benefit that can be derived per kWh of storage system energy storage capacity for each SMO version.

Because of the importance to the overall competitiveness of storage systems, the authors judge this market success metric to be the most important metric of the seven considered (weighting of 25 out of 100).

MSM 4–Economic Benefits Potential (Storage Capacity Potential * Storage Value)

Weighting: 10 out of 100

The extent to which energy storage contributed to the overall U.S. economy (growth and stability) was an important criterion to consider when evaluating the merits and potential significance of related R&D. However, Storage Value was a much more important criterion with regard to catalyzing greater demand for energy storage systems.

MSM 5–Environmental Benefits

Weighting: 13 out of 100

The environmental performance of energy systems is a significant societal issue. If energy storage can contribute even modestly to an overall improvement in the environmental performance of the energy marketplace, it becomes an especially attractive research thrust.

MSM 6–Technology Innovation Opportunity

Weighting: 20 out of 100

For a research effort, it is important that R&D contribute knowledge and experience that leads to meaningful advancement of the technology being investigated. Because this effort did involve R&D, the innovation score was quite important in the context of the SMO evaluation.

MSM 7–Likelihood of Scenario

Weighting: 20 out of 100

Even excellent R&D may be for naught if the business scenario assumed as part of the rationale for said R&D did not come to pass. If so, technological advancement may not result in expected benefits and market success. So, this market success metric was quite important.

These weightings have a significant effect on the quantitative results: they were based, in large part, on judgments by authors, and are certainly subjective.

5. Storage Market Opportunities Scoring

SMOs and SMO Versions Scored

From the twelve SMO versions for which success metrics were calculated (as shown in Appendix A), the four most compelling SMO versions were scored, and those were:

- Two versions of the Power Cost Volatility SMO (1.1a and 1.4),
- One version of the T&D Benefits SMO (2.2), and
- One version that is a combination of the Power Cost Volatility SMO and the T&D Benefits SMO (2.3).

SMOs not scored were: SMO 3) Enhanced Environmental Externalities, SMO 4) Combined Heat and Power Output Smoothing, and SMO 4) Storage System Packaging Breakthroughs. Refer to the respective sections of the report, above, for details about the rationales used to eliminate these SMOs from consideration before the scoring process.

The two Power Cost Volatility SMO versions that were scored bracket the range of potential values for energy storage under plausible scenarios within the Power Cost Volatility SMO. One was from the utility perspective and the other was from the customer perspective.

The third SMO version scored, the “High Value” version of the T&D Benefit SMO, represents locations within utilities’ T&D systems with the highest average cost to serve a kW of customer load.

The fourth SMO version scored was a combination of the High Value T&D Benefits and High Power Cost Volatility SMOs; “high” was defined as 25¢/kWh, based on a proposed electricity price cap in California.

Table 4 provides more details about the four SMO versions scored. Also, Table 5 presents the maximum allowable values (i.e., market saturation levels) for a given market success metric (if applicable) and the average economic benefit for the SMO versions scored.

Table 4. SMOs and SMO Versions Scored

| ID | Perspective | SMO Version Details | Notes |
|--------|-------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1.1.a. | Utility | <p>Power Cost "Super Volatility"</p> <ul style="list-style-type: none"> • 60¢/kWh energy for 100 hours/year • 15¢/kWh energy for 100 hours/year • 205 GW load in-play • Four hours of storage required | <p>The highest plausible power cost assumed is 60¢/kWh energy for 100 hours/year. Assume that user can also “buy low – sell high” at 15¢/kWh during an additional 100 hours per year (i.e., charge when price is low, discharge when price is high).</p> |
| 1.4. | Customer | <p>Electricity Bill Minimization</p> <ul style="list-style-type: none"> • 10¢/kWh on-peak energy • \$60/kW-year demand charge • 650 hours per year storage discharge • 460 GW of load in-play (20% of embedded load and load growth) • Five hours of storage required | <p>Depending on tariff structure commercial and industrial (C&I) customers may have best means to internalize benefits of storage. This version is a reasonable representation of typical “bill reduction” potential for C&I customers.</p> |
| 2.2. | Utility | <p>High T&D Benefits</p> <ul style="list-style-type: none"> • \$90/kW-year <p>Modest Power Cost Volatility</p> <ul style="list-style-type: none"> • 10¢/kWh • 200 hours per year storage discharge • Five hours of storage required • 24 GW Load in-play (.2% of embedded load, 10% of load growth) | <p>Many (and a growing number) of locations within a utility have high cost per kW of T&D capacity added. \$90/kW-year is the assumed value for the 10% most expensive locations. 10¢/kWh for 200 hours per year storage discharge is a reasonable estimate of the cost to generate/purchase power during the most expensive 200 hours within the year (assumed to coincide with T&D capacity needs).</p> |
| 2.3. | Utility | <p>Combination</p> <p>High T&D Benefits</p> <ul style="list-style-type: none"> • \$90/kW-year <p>High Power Cost Volatility</p> <ul style="list-style-type: none"> • 25¢/kWh • 200 hours per year storage discharge • Five hours of storage required • 24 GW Load in-play | <p>This version combines the high T&D value version of the T&D benefits SMO with the “high” power volatility cost of 25¢/kWh – based on the price cap for wholesale electricity in California.</p> |

SMO Scoring: Intermediate Results and Rationale

This section describes the rationale used to establish raw scores (value of 0 to 1) and to calculate weighted scores for each market success metric, for each SMO version. It also shows results from those steps.

SMO Metric Scoring Results

An important step that preceded actual scoring was calculation of *values* for four market success metrics: Power Output Capacity Potential (GW), Storage Capacity Potential (GWh), Storage Value (\$/kW “benefit” per hour of storage capacity), and the Economic Benefits Potential (Storage Capacity Potential * Storage Value). Values are shown in Table 5. For uniformity, the round trip efficiency of energy storage systems used was 65% for all SMO versions. Details are shown in the calculation worksheet in “Appendix A, Table A-2 – SMO Benefit and Market Potential.”

Table 5. Calculated Values for Four Market Success Metrics

| Storage Market Opportunity Version | Market Success Metrics | | | |
|-----------------------------------------------------------------------------------------------------------------------|---------------------------------------|----------------------------------|-------------------------------------------|-----------------------------------------|
| | Power/ Output Capacity Potential (GW) | Storage Capacity Potential (GWh) | Storage Value (\$/kW per hour of storage) | Economic Benefits Potential (\$Billion) |
| 1.1.a. Utility: Power Cost "Super Volatility" (60¢/kWh energy for 100 hours/yr plus 15¢/kWh energy for 100 hours/yr). | 205 | 819 | 137 | 112 |
| 1.4. Customer: Electricity Bill Minimization (10¢/kWh energy, & \$60/kW-yr demand charge, 650 hours per year). | 460 | 2,300 | 175 | 403 |
| 2.2. Utility: High T&D Benefits (\$90/kW-yr) & Modest Power Cost Volatility (10¢/kWh), 200 hours per year. | 24 | 120 | 168 | 20 |
| 2.3. Utility: High T&D Benefits (\$90/kW-yr) & High Power Cost Volatility (25¢/kWh), 200 hours per year. | 24 | 120 | 218 | 26 |

* All scenarios: Assume 3¢/kWh charging energy cost.

Raw Scores for All Market Success Metrics

Raw scores (0 to 1) were assigned to each of the seven market success metrics for the four SMO versions scored and are shown in Table 6. The rationale used to assign raw scores is described later in this section.

Table 6. Storage Market Opportunities Raw Scores

| SMO Version | Market Success Metrics | | | | | | |
|-----------------------------------------------------------------------------------------------------------------------|----------------------------------|----------------------------|---------------|-----------------------------|------------------------|----------------------------------|------------------------|
| | Power/ Output Capacity Potential | Storage Capacity Potential | Storage Value | Economic Benefits Potential | Environmental Benefits | Technical Innovation Opportunity | Likelihood of Scenario |
| 1.1.a. Utility: Power Cost "Super Volatility" (60¢/kWh energy for 100 hours/yr plus 15¢/kWh energy for 100 hours/yr). | 1.00 | 1.00 | .63 | .80 | .10 | .10 | .50 |
| 1.4. Customer: Electricity Bill Minimization (10¢/kWh energy, & \$60/kW-yr demand charge, 650 hours per year). | 1.00 | 1.00 | .80 | 1.00 | .10 | .40 | .40 |
| 2.2. Utility: High T&D Benefits (\$90/kW-yr) & Modest Power Cost Volatility (10¢/kWh), 200 hours per year. | .48 | .40 | .77 | .14 | .10 | .50 | .60 |
| 2.3. Utility: High T&D Benefits (\$90/kW-yr) & High Power Cost Volatility (25¢/kWh), 200 hours per year. | .48 | .40 | 1.00 | .19 | .10 | .80 | .50 |

Score = 1 if SMO-specific Benefits > Average Benefits;
Otherwise Score = SMO-specific Benefits / Average Benefits

Raw Scoring Rationale for Market Success Metrics

Power Output Capacity Potential Raw Scores

The value for this criterion is a function of 1) the technical potential for electric power – existing and growth thereof, and 2) SMO version-specific factors affecting the portion of technical potential that was in play for a given SMO version.

Given the market success saturation assumed of 50 GW, all SMO versions whose Power Output Capacity Potential equals or exceeds 50 GW received a score of 1 for this market success metric. Other SMOs/versions received a score based on the ratio of the load in play for the given SMO version to the 50 GW success saturation level.

Notably, even if energy storage was used to meet just a portion of that 50 GW, then the overall market for storage would grow significantly.

Storage Capacity Potential Raw Scores

This criterion was a function of 1) Power Output Capacity Potential (GW) for the respective SMO version, and 2) SMO version-specific storage capacity requirements (hours).

A rationale similar to the one described for scoring of the Power Output Capacity Potential market success metric was applied to the Storage Capacity Potential metric. As with the Power Output Capacity Potential, even the smallest values calculated for this metric (among SMOs/versions considered) indicated a very significant market potential for energy storage capacity.

The authors assumed that six hours was the maximum practical storage capacity for these types of applications when scoring this success metric. Six hours was the maximum amount of storage required for all SMOs considered initially: six hours were assumed to be needed for SMO version 1.1.b., Moderate Power Cost Volatility. Though the Enhanced Environmental Externalities SMO was not scored, note that for that SMO, energy storage was assumed to be 100 hours.

Consistent with the 50-GW success saturation level for the Power Output Capacity Potential market metric, the authors asserted that the success saturation level for this market success metric was $50 \text{ GW} * 6 \text{ hours} = 300 \text{ GWh}$ during the time horizon of 2001 to 2010.

As with the success saturation level for the Power Output Capacity, even sales equal to a modest portion of that 300 GWh (success saturation level) for energy storage would be very important. Conversely, sales beyond that amount would seem to provide marginal benefit with regard to furthering the cause and overall viability of energy storage.

As a result, SMO versions with Storage Capacity Potentials of 300 GWh or more received a score of 1 for this market success metric. The SMOs with a potential below 300 GWh received proportionally lower scores.

Storage Value Raw Scores

The raw scores for this metric were calculated by normalizing scores to the maximum value (i.e., the maximum value received a score of one and others received a score = to a respective version's value ÷ maximum value).

Economic Benefits Potential Raw Scores

For this metric, any SMO version value exceeding the average for all SMO versions received a raw score of one. Other SMO versions whose value was below the average received a raw score based on the ratio of the respective SMO version's value to the average value calculated for the metric, for all SMO versions.

Environmental Benefits Raw Scores

If it had been scored, the Environmental Externalities SMO was the only one that would have received a raw score of one for this market success metric. All others were assumed to provide significantly less environmental benefits (net of charging losses) via utility system dynamic operating benefits, avoided use of peakers, and enabling cleaner baseload generation to provide a greater proportion of electric energy.

Technical Innovation Opportunity Raw Scores

The authors assumed that the High Power Cost Volatility SMO (version 1.1.a) did not require significant innovation. First, the price differential between on-peak and charging periods/off-peak and a limited number of hours of discharge mean that improved round trip efficiency was not important. Furthermore, few technical improvements to electronics for power output seemed necessary.

Storage system robustness was quite important for what the authors are calling customer bill minimization (version 1.4.) involving demand charge reduction.

For the High T&D Benefits SMO (version 2.2.), the authors contend that improved control and communications, and good power quality output were as important as improved storage system reliability.

Further, if storage is to be used widely for this application, T&D system planners, designers, engineers and operators must have a sense that storage systems can be called upon when needed, conveniently. First of all, that would require storage systems to have the control and communication linkages used by T&D operators. At a minimum, the storage systems' output must not have a negative effect on the grid, and ideally they would enhance power quality and service reliability. Secondly, T&D system operators and designers must believe that systems will be available when needed and will operate reliably.

Similarly, a very robust and reliable system with controls and communication capabilities and high quality power output was needed for the Combination SMO (version 2.3.).

Likelihood of Scenario Raw Scores

Estimates made for the SMO version reflecting customer bill minimization (version 1.4.), involving demand charge reduction, were based on very plausible assumptions about avoidable demand charges and on-peak and charging energy prices.

The authors assumed that the High Power Cost Volatility SMO (version 1.1.a) was somewhat likely to recur during the years of 2000 to 2010. In fact, based on values shown in Appendix B, during the year 2000 in the Pennsylvania, New Jersey, and Maryland region of the U.S., utilities paid an average of 60¢/kWh during the one hundred hours of the year when the wholesale energy price was highest.

The benefits of the Combination SMO (version 2.3.) seemed likely given the fact that there were actual situations involving the “high” T&D benefits and high power cost volatility assumed. Furthermore, the small portion of all load and load growth assumed to be “in-play” was quite modest. Since the high T&D Benefits SMO assumed somewhat less volatile power cost, then it (version 2.2.) seemed even more likely.

Weighted Scoring Results

Final SMO version scores were based on: a) the weightings assigned to each market success metric, and b) the raw score assigned to each metric, a weighted score was calculated for each market success metric, for each of the four SMO versions. Weighted scores for each success metric for each SMO version were summed to calculate the total weighted score for each SMO version, as shown in Table 7.

Table 7. Storage Market Opportunities Weighted Scores

| Storage Market Opportunity Version | Market Success Metrics | | | | | | | Total |
|-----------------------------------------------------------------------------------------------------------------------|----------------------------------|----------------------------|---------------|-----------------------------|------------------------|----------------------------------|------------------------|------------------------|
| | Power/ Output Capacity Potential | Storage Capacity Potential | Storage Value | Economic Benefits Potential | Environmental Benefits | Technical Innovation Opportunity | Likelihood of Scenario | Sum of Weighted Scores |
| 1.1.a. Utility: Power Cost "Super Volatility" (60¢/kWh energy for 100 hours/yr plus 15¢/kWh energy for 100 hours/yr). | 8.0 | 4.0 | 15.7 | 8.0 | 1.3 | 2.0 | 10.0 | 49 |
| 1.4. Customer: Electricity Bill Minimization (10¢/kWh energy, & \$60/kW-yr demand charge, 650 hours per year). | 8.0 | 4.0 | 20.1 | 10.0 | 1.3 | 8.0 | 8.0 | 59 |
| 2.2. Utility: High T&D Benefits (\$90/kW-yr) & Modest Power Cost Volatility (10¢/kWh), 200 hours per year. | 3.8 | 1.6 | 19.3 | 1.4 | 1.3 | 10.0 | 12.0 | 49 |
| 2.3. Utility: High T&D Benefits (\$90/kW-yr) & High Power Cost Volatility (25¢/kWh), 200 hours per year. | 3.8 | 1.6 | 25.0 | 1.9 | 1.3 | 16.0 | 10.0 | 60 |

SMO version 2.3., with high value for utility T&D capacity (\$90/kW-yr) and a volatile on-peak energy price (25¢/kWh) for the 200 hours of the year when electric energy had the highest price, received the highest score (60). If the prevailing energy price during the same 200 hours was only 10¢/kWh (SMO version 2.2.), the score was considerably lower at 49.

The second highest score (59) applied to the SMO version characterized by an electric utility customer using storage to avoid demand charges of \$60/kW-yr and on-peak energy charges of 10¢/kWh for 650 hours per year (SMO version 1.4.).

If electricity prices are “super volatile,” such that the energy price is 60¢/kWh during the utility’s 100 most expensive on-peak hours, and 15¢/kWh for the next 100 most expensive energy hours, then storage used by utilities to serve 200 hours per year of on-peak energy use received a score of 49 (SMO version 1.1.a.).

The authors concluded that a combination of benefits (energy, capacity, and power quality and reliability enhancement) achievable if electric utilities use energy storage systems for high value T&D applications, in regions with high power cost volatility, made energy storage very competitive for about 24 GW and 120 GWh during the years of 2001 to 2010. This amount of energy storage is worth a total of \$26 Billion in gross economic benefits in the U.S., which is the equivalent of \$218/kWh (e.g., constant-year benefits for 2001).

6. Observations, Conclusions and Recommendations

Observations

One important observation regarding the cost-effectiveness of energy storage in general is that (given expected prices for on-peak electricity versus off-peak electricity) storage efficiency has relatively small effects on the net benefits achievable under volatile Power Cost conditions. Figure 2 illustrates this point by showing the benefit (i.e., value per kW of system storage installed) for each SMO version plotted against storage round-trip efficiency—recall that for the actual scoring, 65% efficiency was used. In the figure, note that benefits did not change much between about 45% and 65% round-trip efficiency for the five SMO versions.

The implication for energy storage R&D is that research focused on reducing system capital equipment cost and improving robustness (i.e., sophistication and reliability) may lead to greater market viability over research that solely addresses improved efficiency. Conversely, if storage systems with low round-trip efficiency and low-equipment cost could be developed, they may be quite viable for the Power Cost Volatility SMO, depending on the price differential. The most important implication of this observation is that storage system equipment costs seem much more important than storage efficiency for the Power Cost Volatility SMO.

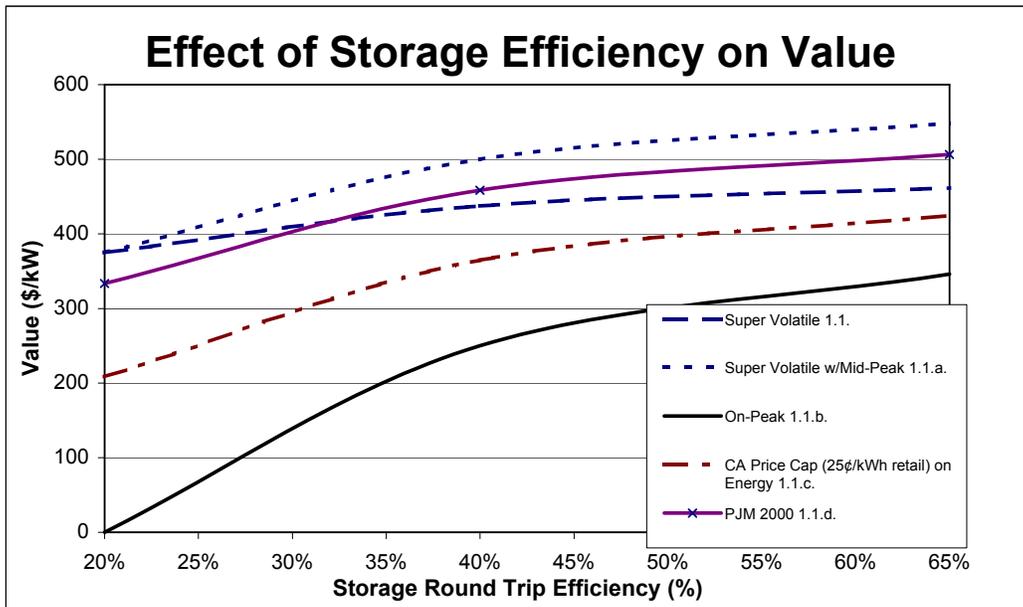


Figure 2. Effect of Round Trip Efficiency on Value

Energy “buy low – sell high” opportunities associated with the Power Cost Volatility SMO and T&D capacity benefits associated with the T&D SMO provide significant benefits by themselves. However, it may be desirable and necessary to combine these two to yield total benefits commensurate with reasonable expectations about storage cost (per kW and per kWh).

In fact, if storage is installed for either of the most significant potential benefits (buy-low / sell-high opportunities associated with the Power Cost Volatility and T&D Benefits), there is little reason not to take advantage of these benefits. The same applies to the improved power quality/reliability benefit; these may accrue depending on where the storage is located.

Conclusions

In the broadest terms, there is significant market potential for all SMOs (relative to existing sales), perhaps several to many tens of gigawatts.

Transmission and Distribution Benefits SMO

Financial benefits associated with the use of energy storage in lieu of electricity T&D capacity can be substantial. In the most compelling situations, T&D upgrades can cost as much as \$90/kW-yr. Using an annualization factor of 0.12, the \$90 figure results in a value for each kW of storage system of about $\$90/\text{kW-yr}/0.12 = \750 kW (without regard to the value of the energy stored and discharged).

Though that applies to only about 10% of all load growth, the market potential is still a very attractive 24 GW from 2001 to 2010. Appendix A outlines the details.

Power Cost Volatility SMO

Overall, the potential for this SMO was very significant given the load in play and the price differentials (between those prevailing during peak demand periods and those during off-peak demand/price periods) expected as deregulation proceeds. There were many ways to participate in the Power Cost Volatility SMO, which applied to both utilities and customers. The key factor that determines whether a utility or customer would be best able to internalize benefits involves the utility’s actual cost, the price charged to a given class or group of customers, and the ways those prices manifest themselves in utility rates and tariffs.

For example, it was less advantageous to use energy storage if demand charges were equal throughout the year than if demand charges were higher during peak demand months. The same applied to energy prices; that is, customers paying a single average price for electric energy throughout the year cannot internalize benefits like a utility customer whose tariffs charge “time-of-use” (i.e., time-specific) prices for electric energy.

Enhanced Environmental Externalities SMO

The use of energy storage to enable environmentally sound generation can be viable if externality credits are on the order of \$0.10/kWh and if storage systems can operate

enough to satisfy electric demand for about 5,000 hours per year. If so, the revenues would cover the cost for wind generation capacity at about \$100/kW-yr, which would leave revenues to cover the costs of the energy storage plant of about \$350/kW-yr.

But, if externality credits are much below \$0.10/kWh, then there is not enough of a premium to cover the cost for wind generation capacity and to provide revenues needed to cover costs of the energy storage plant.

Despite this observation, the likelihood that such a high externality credit will apply is quite low. Unless the cost for electricity generated using wind drops, and/or the cost to generate using fossil-fueled generation plants increases significantly, wind generation-plus-storage plants will have a difficult time competing with fossil-fueled plants.

Furthermore, there is a strong push to reduce emissions from combustion generation technologies of all types and sizes, so the relative importance of environmental benefits possible from storage plus non-polluting renewables may diminish over time.

The Most Promising SMO for Further Investigation

Given the premise that storage systems installed for a given SMO can provide benefits associated with other SMO versions, the authors concluded that some combination of the Power Cost Volatility SMO and the T&D Benefits SMO would be the most compelling for further investigation. Specifically, a combination of benefits (energy, capacity, and power quality/reliability enhancement) achievable using energy storage systems for high value T&D applications, in regions with high power cost volatility, makes storage very competitive for about 24 GW and 120 GWh during the years of 2001 to 2010. This represents significant market potential.

Recommendations

The authors recommend that phase three of this project involve the development of a business plan to exploit the market potential associated with a combination of the High T&D Benefits and High Power Cost Volatility SMO versions. The estimated market potential is 24 GW and 120 GWh. The storage was assumed to be worth \$218/kWh installed, and benefits achievable (if all of the 120 GWh is installed) are \$26 Billion between the years 2001 and 2010.

The focus of such a business plan would be on two specific areas: 1) the marketing planning portion of the business planning effort, and 2) technological requirements for storage if it is to serve the High T&D Benefits/High Power Cost Volatility SMO version.

The final product would be a business plan that provides a more detailed definition of the opportunities available, technology characterization (of storage systems needed to exploit the SMO selected for additional investigation), and a body of information that reflects the views of technology developers and utility engineers and planners.

The following is a list of potential business plan themes and facets:

- Interviews with T&D engineers to inventory, categorize, characterize, and generalize T&D hot spots;
- Evaluation of electric utility customer tariff structures and the potential to reduce cost for electricity, and of customers' market acceptance of storage technologies;
- Interviews with storage developers
 - for input to technology plan, and
 - to refine storage cost targets;
- Continue to evaluate the opportunities for storage by ESCO members;
- Further investigation of the opportunity to develop low capital cost versus systems with "low" storage round-trip efficiency;
- Additional investigation of the opportunity to develop storage systems that enable hybrid energy systems;
- Additional investigation of the opportunity to reduce air emission impacts either by:
 - exploiting technical synergies among clean generation and energy storage, or
 - taking advantage of emission offsets trading;
- Further investigation of the opportunity to improve PQ and reliability;
- Further investigation and quantification of "localized" benefits/facets for electric utilities.

Appendix A – SMO Benefit and Market Potential Estimation Worksheet

Tables A-1 and A-2, on the following pages, show two parts of the SMO Benefit and Market Potential Estimation Worksheet. Table A-1 shows assumptions, while Table A-2 shows intermediate calculations and scoring results.

Table A-1 includes assumptions about load in play, customer energy use, value of energy (kWh) and capacity (kW) to utilities, energy storage systems' energy and power output needs, and electric utility prices for demand (kW) and energy (kWh), for all SMO versions considered (of which four were ultimately scored).

Table A-2 indicates cost savings and benefits associated with storage used for the respective SMO version.

Note that some data appear in both tables: some assumptions are included in Table A-2, specifically load in play, energy storage system requirements (output and storage capacity), and annual hours of storage system discharge for a given SMO version.

Table A-1. SMO Assumption Details

Scenario 65% Efficient Storage

Utility System

| | | | | | | | |
|--|-------------|-----------|--------------------|------------------|---------------------------------|--------------------------|----------------------------|
| | System Load | Peak (GW) | System Load Factor | Load Growth Rate | System Energy Use, Year 1 (GWh) | Load Growth, Year 1 (GW) | Load Growth, 10 Years (GW) |
| | | 800 | 0.6 | 2.5% | 4,204,800 | 20 | 224 |

Timeframe and Financial

First Year 2000
 Number of Years 10
 Annualization Factor .1200

Utility Tariff

Off-Peak Energy Price (\$/kWh) .030
 Monthly Demand Charge (\$/kW-mo) 10.0
 Months During which Demand Charges Apply 6

Load Segments

Commercial Industrial Residential
 Portion of Load 30.0% 30.0% 40.0%

Storage Plant

Storage Round Trip Efficiency (%) 65.0%

| Note | Super Volatile Power Cost 1.1. | Super Volatile Power Cost w/Mid-Peak 1.1.a. | Moderate Power Cost Volatility 1.1.b. | High Power Cost Volatility 1.1.c. | PJM "Market" Power Cost 2000 1.1.d. | High Power Cost Volatility Plus Average T&D 1.2. | High Power Cost Volatility Plus PQ 1.3. | Modest Power Cost Volatility plus PQ & Demand Reduction 1.4. | Top 50% T&D Value, Modest Power Cost Volatility 2.1. | Top 10% T&D Value, Modest Power Cost Volatility 2.2. | Top 10% T&D Value, High Power Cost Volatility 1.1.a. & 2.2 2.3. | Externalities 3. |
|--------------------------------------------------|------------------------------------------------------|---------------------------------------------|---------------------------------------|-----------------------------------|-------------------------------------|--------------------------------------------------|-----------------------------------------|--------------------------------------------------------------|-----------------------------------------------------------------|------------------------------------------------------|-----------------------------------------------------------------|---------------------------------|
| Technical Potential (description) | <-- 20% of embedded load plus 20% of load growth --> | | | | | all load growth | 1/3 of embedded C&I load and growth | 75% of C&I load and growth | 1%/2% of embedded load ("attrition") and 50%/10% of load growth | | .2% of embedded load ("attrition") and 10% of load growth | 50% of embedded load and growth |
| Portion of Embedded Load in Play | .20 | .20 | .20 | .20 | .20 | 0 | .20 | .45 | .01 | .0020 | .0020 | .50 |
| Portion of Load Growth in Play | .20 | .20 | .20 | .20 | .20 | 1.00 | .20 | .45 | .50 | .10 | .10 | .50 |
| Electric Energy Price (\$/kWh) | .60 | .60 | .15 | .25 | .35 | .25 | .25 | .10 | .10 | .10 | .25 | n/a |
| Diurnal Hours Required (kWh/kW _{out}) | 4 | 4 | 6 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | n/a |
| Energy Storage Required (kWh/kW _{out}) | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 100 |
| Annual Hours of Discharge | 100 | 100 | 400 | 250 | 200 | 250 | 250 | 650 | 200 | 200 | 200 | 5,000 |
| Mid-Peak Energy Price (\$/kWh) | | .15 | | | | | | | | | | |
| Mid-peak Annual Hours of Discharge | | 100 | | | | | | | | | | |
| Demand Charges Avoided (\$/kW-year) | | | | | | | | 60.0 | | | | |
| T&D Credit (\$/kW-year) | | | | | | 30.0 | | | 50.0 | 90.0 | 90.0 | |
| PQ Credit (\$/kW-year) | | | | | | | 10.0 | 10.0 | | | | |
| Externality Credit (\$/kWh) | | | | | | | | | | | | .100 |

Table A-2. SMO Benefit and Market Potential

| | Super Volatile Power Cost 1.1. | Super Volatile Power Cost w/Mid-Peak 1.1.a. | Moderate Power Cost Volatility 1.1.b. | High Power Cost Volatility 1.1.c. | PJM "Market" Power Cost 2000 1.1.d. | High Power Cost Volatility Plus Average T&D 1.2. | High Power Cost Volatility Plus PQ 1.3. | Modest Power Cost Volatility plus PQ & Demand Reduction 1.4. | Top 50% T&D Value, Modest Power Cost Volatility 2.1. | Top 10% T&D Value, Modest Power Cost Volatility 2.2. | Top 10% T&D Value, High Power Cost Volatility 1.1.a. & 2.2 2.3 | Extern- alities 3. |
|--------------------------------------------------|--------------------------------------------------|---------------------------------------------|---------------------------------------|-----------------------------------|-------------------------------------|--------------------------------------------------|-----------------------------------------|--------------------------------------------------------------|-----------------------------------------------------------------|------------------------------------------------------|----------------------------------------------------------------|---------------------------------|
| Note | utility | utility | utility | utility | utility | utility | C&I customer | C&I customer | utility | utility | utility | societal |
| Load in Play (description) | ← 20% of embedded load plus 20% of load growth → | | | | | all load growth | 1/3 of embedded C&I load and growth | 75% of C&I load and growth | 1%/2% of embedded load ("attrition") and 50%/10% of load growth | | | 50% of embedded load and growth |
| Embedded Load (GW) | 160 | 160 | 160 | 160 | 160 | 0 | 160 | 360 | 8 | 2 | 2 | 400 |
| Load Growth All Years | 45 | 45 | 45 | 45 | 45 | 224 | 45 | 101 | 112 | 22 | 22 | 112 |
| All Years (GW) | 205 | 205 | 205 | 205 | 205 | 224 | 205 | 461 | 120 | 24 | 24 | 512 |
| Energy Storage Capacity (kWh/kW _{out}) | 4.0 | 4.0 | 6.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 100.0 |
| Net Value of Energy (\$/kWh) | .554 | .554 | .104 | .204 | .304 | .204 | .204 | .054 | .054 | .054 | .204 | .000 |
| Annual Hours of Discharge | 100 | 100 | 400 | 250 | 200 | 250 | 250 | 650 | 200 | 200 | 200 | 5,000 |
| Net Value (\$/kW-year) * | 55.4 | 55.4 | 41.5 | 51.0 | 60.8 | 51.0 | 51.0 | 35.0 | 10.8 | 10.8 | 40.8 | 0.0 |
| Mid-Peak Net Energy Savings (\$/kW-year) * | 0.0 | 10.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Demand Charges Avoided (\$/kW-year) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 60.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| T&D Credit (\$/kW-year) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 30.0 | 0.0 | 0.0 | 50.0 | 90.0 | 90.0 | 0.0 |
| PQ Credit (\$/kW-year) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 10.0 | 10.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Externalities Credit (\$/kW-year) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 500.0 |
| Total Benefit (\$/kW-year) | 55.4 | 65.8 | 41.5 | 51.0 | 60.8 | 81.0 | 61.0 | 105.0 | 60.8 | 100.8 | 130.8 | 500.0 |
| \$/kW | 462 | 548 | 346 | 425 | 506 | 675 | 508 | 875 | 506 | 840 | 1,090 | 4,167 |

* scenario-specific discharge hours *
(scenario-specific energy price - (off peak energy price / storage round trip efficiency))

| | | | | | | | | | | | | |
|------------------------|-------|-------|------|------|-------|-------|-------|-------|-------|-------|-------|------|
| \$Gross/kWh of Storage | 115.4 | 137.0 | 57.7 | 84.9 | 101.3 | 134.9 | 101.6 | 175.0 | 101.3 | 167.9 | 217.9 | 41.7 |
|------------------------|-------|-------|------|------|-------|-------|-------|-------|-------|-------|-------|------|

Appendix B – PJM Energy Cost, Top 200 Load Hours, Year 2000

| Load Duration Hours | | | Energy Value | | Charging Cost | | | Net Value | |
|---------------------|-----------|----------------|------------------------------|--------------------------------|-------------------------------|--------------------------------|------------------------------|-------------------|-----------------------|
| First Hour | Last Hour | Hours Per Year | Average Energy Price (¢/kWh) | Annual Energy Value (\$/kW-yr) | Charging Energy Price (¢/kWh) | Charging Energy Cost** (¢/kWh) | Annual Charging Cost (\$/kW) | Annual (\$/kW-yr) | Cumulative (\$/kW-yr) |
| 1 | 43 | 43 | 93.0 | 40.0 | 3.0 | 4.6 | 2.0 | 38.0 | 38.0 |
| 44 | 94 | 51 | 40.0 | 20.4 | 2.0 | 3.1 | 1.6 | 18.8 | 56.8 |
| 95 | 200 | 106 | 9.0 | 9.5 | 2.0 | 3.1 | 3.3 | 6.3 | 63.1 |
| 201 | 1,000 | 800 | 5.0 | 40.0 | 2.0 | 3.1 | 24.6 | 15.4 | 78.5 |
| 1,001 | 2,000 | 1,000 | 2.8 | 28.0 | 1.5 | 2.3 | 23.1 | 4.9 | 83.4 |

**Round Trip Efficiency 65%

| | Hours Per Year | Average Energy Price (¢/kWh) | Annual (\$/kW-yr) |
|------------|----------------|------------------------------|-------------------|
| Bin 1 | 43 | 93.0 | 40.0 |
| Bins 1 - 2 | 94 | 64.2 | 60.4 |
| Bins 1 - 3 | 200 | 35.0 | 69.9 |
| Bins 1 - 4 | 1,000 | 11.0 | 109.9 |
| Bins 1 - 5 | 2,000 | 6.9 | 137.9 |

Appendix C –Financial and Emissions Benefits

Table C-1. Example Emissions Benefits of Storage

Case: Example of Emissions Reduction from Storage Use

| | | | |
|---------------------------------------------|-----------|----------|----------|
| | On-Peak | Mid Peak | Off-Peak |
| Generation Operation Hours (hours/year) | 200 | 4,000 | 8,000 |
| "Markup" (% of Energy Unit Cost) for Resale | not used | 10% | 5% |
| Storage Round Trip Efficiency 65% | | | |
| | Discharge | Charge | |
| Storage Operation Hours (hours/year) | 1,000 | 1,538 | |

| Item | Fuel Price \$/MMBtu | Heat Rate Btu/kWh | Non Fuel Cost* \$/kWh | T&D I ² R Loss Factor % | Period-Specific Energy Unit Cost** \$/kWh | Energy Annual Cost*** \$/kW-yr | Marginal Plant NOx Emission Factor lbs/kWh | Marginal Plant CO ₂ Emission Factor lbs/kWh | Net** NOx Emission Factor lbs./kWh | Net** NOx Emissions lbs/kW-yr | Net** CO ₂ Emission Factor lbs./kWh | Net** CO ₂ Emissions lbs/kW-yr |
|------------------|------------------------|----------------------|--------------------------|---------------------------------------|----------------------------------------------|-----------------------------------|-----------------------------------------------|-----------------------------------------------------------|---------------------------------------|----------------------------------|---------------------------------------------------|----------------------------------------------|
| On-Peak Energy | | | .15 | .07 | .161 | 32.3 | .00200 | 1.400 | .00215 | 0.4 | 1.51 | 301 |
| Mid Peak Energy# | 3.0 | 10,500 | .01 | .05 | .044 | 174.7 | .00075 | 1.100 | .00079 | 3.0 | 1.16 | 4,632 |
| Off Peak Energy | 3.0 | 9,000 | .005 | .03 | .035 | 277.1 | .00011 | .950 | .00011 | 0.8 | 0.98 | 7,835 |

* May include: 1) O&M and/or 2) wholesale purchase price, and/or 3) any other variable charges/cost.
 ** Including 1) direct cost, 2) markups and 3) T&D I²R Losses.
 *** Based on 1) period-specific energy unit cost and 2) generation operation hours per year.
 # Price for avoided electricity purchases (i.e., avoided due to storage discharge) not within on-peak price/cost period.

| Item | Energy Unit Price (from Utility) \$/kWh | Energy Unit Net Cost \$/kWh | Energy Annual Cost*** \$/kW-yr | Net NOx Emission Factor lbs./kWh | Annual NOx Emissions*** lbs/kW-yr | Net CO ₂ Emission Factor lbs./kWh | Annual CO ₂ Emissions*** lbs/kW-yr |
|-------------------------|--------------------------------------------|--------------------------------|-----------------------------------|-------------------------------------|--------------------------------------|-------------------------------------------------|--------------------------------------------------|
| Energy Purchases Offset | .071* | .071* | 70.7 | .00163* | 1.63 | 1.51* | 1,507 |
| Charging Energy | .035 | .056** | 56.0 | .00017** | 0.17 | 1.89** | 1,888 |
| Net Benefit | .036 | .015 | 14.7 | .00147 | 1.47 | .382 | 382 |
| Reduction per kWh (%) | 26.4% | | | 877.8% | | 20.2% | |

* Composite based on 1) period-specific utility value -- cost or emissions -- per kWh) and 2) annual discharge hours.
 ** Based on 1) utility off-peak value -- cost or emissions -- per kWh and 2) round trip efficiency losses.
 *** Based on 1) net value -- cost or emissions -- per kWh and 2) hours of discharge.

End Notes

- 1 Iannucci, J., Schoenung, S., “Energy Storage Concepts for a Restructured Electric Utility Industry,” SAND2000-1550, Sandia National Laboratories, Albuquerque, NM, July 2000.
- 2 Zaininger, H., “Analysis of the Value of Battery Energy Storage with Wind & Photovoltaic Generation to the Sacramento Municipal Utility District,” SAND98-1904, Sandia National Laboratories, Albuquerque, NM, August 1998.
- 3 Iannucci, J., Eyer, J., Horgan., Schoenung, S., “Coupling Renewables via Hydrogen into Utilities: Temporal and Spatial Issues, and Technical Opportunities,” DE-FC36-90-G010140, U.S. DOE, May 1997.
- 4 Please visit the website for PowerPaper’s manufacturer to view products, Thinergy Ltd, at <http://www.powerpaper.com>.
- 5 Iannucci, J., Eyer, J., Cilbulka, L., “Economic Market Potential for Utility Owned Distributed Generation,” Edison Electric Institute, October 2001.

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