The Brattle Group

Analysis of Benefits:
PSE&G's Energy Strong Program

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PSEG
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EXECUTIVE SUMMARY

PSE&G requested that *The Brattle Group* review the company's Energy Strong (ES) program submitted to the New Jersey BPU in February 2013, and estimate the benefit potential that may be realized from these investments.

The ES program makes PSE&G's utility infrastructure either "harder" (i.e., avoiding outages) or more resilient (i.e., reducing the duration of outages), and is designed to mitigate outages to electric and gas service that would otherwise occur as a result of major weather events. These investments benefit customers in that some of the outages that they would otherwise experience are mitigated. The ES investments also provide benefits to the public overall. For example, the mitigation of outages in utility services reduces the losses in wages to workers and tax revenues to governments that would otherwise have accompanied interruptions in business operations.

The primary private beneficiaries of outages mitigated through the ES program are PSE&G's customers. Economic research and analysis provides an estimate of the value that electric and gas customers place upon avoiding outages to their electric and/or gas services. We used these values, which vary among classes of customers and type of service, together with PSE&G engineers' estimates of the impact that the ES sub-programs are projected to have upon mitigating outages, as the basis for estimating the benefits of the ES program to PSE&G's customers.

The Electric ES program will result in reductions in the number and duration of outages caused by severe weather events, and will, accordingly, provide value to customers. We found that this value is equal to PSE&G's Electric ES cost, or "breaks even," when the total outages have a cumulative duration of about three days – either through a single major future weather event, such as another Superstorm Sandy, or from the combination of lesser weather events taking place over the course of the life of the Electric ES assets. Looking back over recent history, the Electric ES investment would have more than been paid for if it were in place in 2011, prior to the outages caused by Hurricane Irene, the October 2011 snowstorm and Superstorm Sandy in 2012.

On the gas side, we found that outages of slightly more than seven days – again, either through a single event or from several lesser events – would "break-even" in that the improvements would provide benefits to gas customers sufficient to cover the cost of PSE&G's Gas ES investment.

There are also significant public benefits associated with the ES investments. For example, a macroeconomic analysis conducted by the Edward J. Bloustein School of Planning and Public Policy at Rutgers University found that Superstorm Sandy was responsible for roughly $12 billion in lost economic activity, 7,300 job losses, significantly lower tax revenues and higher governmental costs in 2012 alone, and will have ongoing economic impacts into the future. The Energy Strong program would have reduced these losses and also create an estimated 5,325 jobs over the next decade. The additional economic benefits to the State of New Jersey from these new jobs are not considered as part of this study; however, these benefits could be material. In addition, the Gas ES investments address improving gas pipe safety, reducing lost gas that is paid for by consumers, and reducing the environmental cost of methane emissions. We estimate that the benefits from reducing leakage and methane emissions will be approximately $5.7 million per year. These are also important benefits that we do not include in our break-even analysis, but which should be taken into account in assessing the overall benefits associated with the ES program.

PSE&G's Energy Strong Program

The proposed ES investment program is composed of four investment areas, three addressing electric infrastructure and one addressing gas infrastructure:

- **Electric Infrastructure (Asset) Hardening** covers ten sub-programs, including station flood and storm surge mitigation, enhancement of outside plant construction standards, strengthening pole infrastructure, undergrounding parts of the overhead system that are particularly susceptible to storm damage, and relocating operations and emergency response centers.

- **Electric System Resiliency** covers eight sub-programs and is primarily concerned with applying advanced technologies (such as remote controls, sensors and broadband communications) to improve system visibility and improve outage detection and responsiveness. It also involves applying smart switches and fuses and adding them within PSE&G's loop scheme.

- **Electric Supplemental Investment** covers two sub-programs, one involving backup generators and the other a pilot program to engage municipal resources in vegetation management and in storm responses.

- **Gas Delivery Infrastructure Hardening** covers two sub-programs, one involving hardening nine of PSE&G's metering and regulation (M&R) stations and the Burlington LNG and LPG storage facilities; and the other replacing 750 miles of utilization-pressure cast iron (UPCI) mains and 40,000 steel service pipes in municipalities with records of flooding, and installing excess flow valves (EFVs) wherever services are replaced for single family dwellings.

The total investment cost for the ES program is approximately $3.9 billion (in 2012 dollars), which we estimate to be roughly $2.9 billion on a present value (PV) basis. PSE&G has proposed that it will invest approximately $2.6 billion in the first phase of the ES program (months 1 - 60) and the remaining $1.3 billion in a second phase (months 61 – 120). The majority of this investment cost, about $2.8 billion, is associated with PSE&G's electric system; the remaining investment, over $1.1 billion, is planned for the company's gas system.

Benefit Valuation Approach

The stated purpose of the ES program is to harden and enhance the resilience of PSE&G's electricity and natural gas service. Such investments benefit customers by reducing the likelihood that severe weather will cause electric or gas outages and/or by reducing the duration of outages should they occur. Specifically, asset hardening should reduce the number of customers who experience outages and resiliency related investments should reduce the duration of outages for those customers who have their utility service interrupted. Thus, PSE&G's ES investments do not necessarily "pay for themselves" by, for example, reducing operating costs. Instead, the benefit associated with PSE&G's ES investments can be derived by estimating the number of hours of customer outages during major weather events that would be mitigated due to the ES investments, and in turn estimating the value that customers place upon avoiding hours of interruptions to their utility services as a result of those major weather events. PSE&G's ES investments will likely also provide substantial *public* economic benefits, including reduced losses of wage and tax revenues and benefits associated with increased employment, and will also likely improve electric and gas system reliability under more normal weather conditions. We did not quantify these additional areas of benefit in our analysis.

We estimated the *private* benefit potential stemming from severe weather events to PSE&G's customers in two primary steps. First, we reviewed the customers that are targeted to be affected by each sub-program, and the impact (as estimated by PSE&G's engineers) that the sub-programs are likely to have on mitigating service interruptions stemming from major weather events. Second, we reviewed existing economic research and developed an analytical approach to estimate the value to customers of having outages mitigated.

The product of the value that customers place upon avoiding outages and the degree of outage mitigation projected to result from the ES investments, combined with an assumed duration of a major outage event, provides an estimate of the benefits that may be realized by customers from PSE&G's ES investments. Such an estimate of value is informative but largely illustrative because it is based on a single point estimate of outage duration; that is, it provides an indication of the benefits that would likely accrue to customers under *specific* outage circumstances, e.g., the benefit of an estimated reduction in the number of customer outage hours that would have occurred, in the absence of the ES investments, during a 24-hour system outage. In practice, outages caused by major weather events may be longer than that assumed, or may not happen at all. Thus, it is important to recognize that it not possible to estimate the *expected value* of benefits associated with PSE&G's ES investments without specifying the probabilities of severe weather events affecting PSE&G's customers in the future. These probabilities are not presently available.

As an alternative, we find that a "break-even" analysis may be more informative to policy makers in assessing the value of PSE&G's ES program. Specifically, in the break-even analysis we estimate the cumulative duration of mitigated outages that would produce a level of value to customers equal to the PV cost of PSE&G's ES investment program. Alternatively stated, the break-even analysis solves for the cumulative duration of mitigated outages associated with major weather events that would have to occur in order for PSE&G's ES investment to provide value to customers sufficient to cover their investment cost. Comparing the break-even outage duration to recent outage histories provides context for determining whether or not the ES investment is worth making. We conduct a break-even analysis separately for PSE&G's Electric and Gas ES sub-programs.

Benefits from Electric ES Investment

PSE&G served nearly 2.2 million electric customers who consumed roughly 41.3 billion kWhs in 2012. Based on these data, a system-wide power outage lasting 24 hours would result in 51.7 million hours of customer interruptions which, in turn, translates into approximately 113 million unserved kWhs. Some Electric ES sub-programs (such as Advanced Technology, System Resiliency) are targeted at all PSE&G customers, while other sub-programs (such as Asset Hardening, Rebuilding Backyard Poles) benefit specific segments of customers. PSE&G's engineers reviewed and analyzed the Electric ES sub-programs to determine how many customers would be affected by these investments and whether or not those customers, as a result, would avoid prolonged outages and/or whether they would realize reduced outages (and by how much).

Adding up the impacts associated with the Electric ES sub-programs that address individual circuits and substations indicated that over the course of a 24 hour system-wide outage caused by a major weather event, roughly 12.4 million hours of outage would be avoided and/or reduced as a result of the circuit and substation based sub-programs, which translates into mitigation of about 26.5 million unserved kWhs. The impacts of the ES investments concerning Advanced Technologies and Relocations of Operations Centers, which affect a broader scope of customers, was estimated to sum to a reduction of approximately 2.9 million customer-hours of outage or mitigation of about 6.4 million unserved kWhs. This totals to roughly 15.3 million hours of outage that were avoided and/or reduced, or approximately 32.9 million unserved kWhs being mitigated over the course of an assumed 24 hour outage caused by a major weather event.

PSE&G's analysis also estimated the mix of customers affected by the Electric ES program (*i.e.*, residential, commercial and industrial). This is an important consideration when estimating the value that customers place on mitigating power outages because research has indicated that such value varies by class of customer. The value that customers place on mitigating power outages is referred to as the "value of lost load," or VOLL. VOLLs represent the values to customers of avoiding the loss of power; that is, estimates of the economic damages that they would realize as a result of a power outage. Of course, these values are not the cost basis to the electric utility, nor are they the price that an electric utility would charge its customers. A widely accepted study on VOLL was reported by the Lawrence Berkeley National Laboratory (the Berkeley study) and in our analysis we find that the results from this Berkeley study should be generally applicable to customers in New Jersey.

Matching the mitigated unserved kWhs for each customer class realized over the course of a 24 hour system-wide outage (totaling 32.9 million unserved kWhs, as described above) with the VOLLs estimated for each customer class produces a benefit of approximately $957 million, which would be realized by PSE&G's electric customers over the course of the assumed 24 hour outage caused by a major weather event. A more reasonable estimate of the cumulative duration of outages resulting from major weather events over the course of a few years may be three days, considering that the average outage duration of affected customers following Superstorm Sandy, a single major weather event, was roughly 3.5 days. Following from this, the benefits to customers from the Electric ES program of mitigating a three day outage would be roughly $2.87 billion.

In practice, it is likely that a major event will affect all or even most points of failure at the same time. Furthermore, restoration efforts following wide-spread outages caused by storms will at least partially be completed in parallel. Thus, the above estimates of outages avoided and/or reduced during the course of a 24 hour outage represent non-coincident estimates and likely overstate the impact. We adjusted for this *coincidence* when analyzing the overall outage benefits of PSE&G's Electric ES sub-programs. We assumed that 33% of the outage hours following a severe weather event are contemporaneous, thereby reducing the aggregate customer outage-hours by 33%. Applying this coincidence factor to the three day outage example above reduces the benefits to customers from the Electric ES program from $2.87 billion to roughly $1.92 billion.

The benefits to customers resulting from mitigated outages over the course of a three day outage of $1.92 billion is slightly lower than the PV of the Electric ES investment cost (*i.e.*, nearly $2.0 billion). We estimate that the cumulative duration of outages mitigated necessary to produce a value to customers equal to the PV of PSE&G's Electric ES investment (*i.e.*, its break-even point) is approximately 3.08 days. That is, PSE&G's Electric ES investment will "pay for itself" if the utility's customers are faced with outages occurring over the course of the life of the

Electric ES assets that sum to roughly 3.08 days. This appears to be a low threshold considering the average outage durations was roughly 3.5 days for Superstorm Sandy, 0.83 days Hurricane Irene and 0.94 days for the October Snowstorm. Together, the average outage to affected customers from these weather related outages alone was nearly 5.3 days.

Benefits from Gas ES Investment

PSE&G provided gas service to approximately 1.8 million customers in 2012. The company's engineers estimate that roughly 602,000 gas customers will be affected by the Gas ES sub-program concerning hardening the company's M&R stations and nearly 63,000 gas customers will be affected by the sub-program that replaces UPCI mains and steel service pipes and installs EFVs.

Gas outages tend to be less frequent than electric outages, and storm related outages in the gas system are typically less extensive than is the case for electric outages. However, gas customers can and do experience outages due to localized piping breaks, meter failures, water ingress in local mains, and/or system-wide failures involving the loss of pressure due to large scale disruptions. Furthermore, when they do occur, gas outages tend to have longer durations than electric outages. Approximately 6,800 customers lost gas service due to meter failures and flooding within PSE&G's service area during Superstorm Sandy.

Unlike our analysis of the Electric ES program, however, research and studies concerning the value of lost load is less available for gas customers than it is for electric customers. We used two methods for approximating the VOLL equivalent for PSE&G's gas customers: 1) consumer surplus, which we use as an indicator of the value that residential customers place upon avoiding gas outages, and 2) value added (an approximation for profit margins), which we use to estimate the value that commercial and industrial (C&I) customers place upon avoiding gas outages.

Consumer surplus is the difference between the price paid and the maximum price that the consumer would have been prepared to pay. Similar to the values estimated in the VOLL analysis that was applied to electric customers, the consumer surplus for residential gas customers provides an indication of customer *willingness to pay*. Consumer surplus can be estimated by approximating the demand curve for PSE&G's residential gas customers and estimating the area under the curve between the average price paid and the maximum price that customers would be prepared to spend for gas service. We estimated the demand curve for PSE&G's residential customers by applying the price elasticity (*i.e.*, the degree to which customers respond to a change in price) to recently observed actual prices and quantities. We found that the consumer surplus for PSE&G's residential gas customers is roughly $53 per customer per day. On a monthly basis, this varies from consumer surplus levels below $10 per month during the non-heating season to levels of roughly $100 or more during the heating season. As a check, we compared this to the average VOLL estimated for PSE&G's residential electric customers (about $18 per day). The difference between the averages is largely explained by the value that residential customers place upon being able to heat their homes.

PSE&G's gas C&I customers also place a value on avoiding the loss of gas service. Loss of gas service can result in reduced or shut-down operations for some business segments. Similar to the VOLL estimated for electric C&I customers, the value of avoiding gas outages to a customer may be equal to but should not exceed its profit margin. "Value added" measures the value that a business adds to a State's Gross State Product (GSP). The GSP for New Jersey and the data to estimate value added are provided by category of C&I customer by the U.S. Department of Commerce. We estimated the average value added for PSE&G's gas C&I customers to be approximately $1,775 per C&I customer per day. This value is considerably lower than the VOLL for electric C&I customers, which we estimated to be more than $11,000 per day per electric C&I customer on average. This difference can be explained by the nature of C&I business applications and processes, which are generally more dependent upon reliable electric service than upon reliable gas service (except for those instances in which industrial processes rely heavily on natural gas as a fuel). Thus, setting electric VOLLs higher than the value levels used for gas service is internally consistent.

Using the above values to customers of avoiding the loss of gas service and the number of residential, commercial and industrial gas customers affected by PSE&G's Gas ES sub-programs, we estimated that the impact of the Gas ES investments over a five day outage for all gas customers would result in benefits to gas customers equal to roughly $640 million. We also estimated the break-even duration of gas outages necessary so that the value to customers equals the PV of the Gas ES investment (roughly $907 million). We estimate this break-even to be slightly over seven days cumulatively of gas outages over the life of the Gas ES assets in order for PSE&G's Gas ES investment to "pay for itself."

The break-even outage duration is lower for the Gas ES sub-program that addresses hardening PSE&G's M&R stations because these investments affect numerous gas customers. On the other hand, the Gas ES sub-program that addresses replacing UPCI mains and steel service pipes affects individual customer connections, so recovery of the associated investment cost is spread over fewer and nearly exclusively residential customers. It therefore requires a significantly longer outage duration in order for the sub-program investment to break-even based on the categories of benefit we considered. However, it is important to recognize that replacement of aging gas pipes has received considerable attention across the country because, among other things, leaking gas pipes result in the release of methane, a greenhouse gas, into the atmosphere. Replacing aging pipes will reduce methane emissions. We did not include these very significant benefits, nor the benefits of increased employment associated with the UPCI sub-program, in our analysis.

Conclusions

On a combined basis the benefits projected to be realized by customers from PSE&G's Electric ES investment mitigating a three day electric outage (roughly $1.92 billion) and PSE&G's Gas ES investment mitigating a five day gas outage (approximately $640 million) is nearly $2.6 billion. However, 57% of PSE&G's customers are served on a combined basis (i.e., they receive both electric and gas service). Those customers incur costs and/or lose value because they are unable to remain in their residences and/or are unable to carry on production and business. The impact on customers (in terms of lost value) from outages in both electric and gas services likely exceeds the impact of losing only one utility service but is less than the additive effect of the values lost separately for electric and gas service. We adjusted for the impact of PSE&G customers that receive combined electric and gas service, and estimate that the value realized by customers from mitigating a three day electric outage and a five day gas outage is nearly $2.2 billion.

As mentioned earlier, the above value analysis is based on the assumption of a single outage duration, which is unknowable. We also reported that the break-even cumulative duration of outages necessary to produce value to electric customers equal to the PV of the Electric ES is 3.08 days, and the analogous break-even for gas customers is roughly 7.08 days. These break-even metrics can change as assumptions are modified, particularly those concerning the value to customers of mitigating an outage in their utility service. Notably, the break-even for the Electric ES investment could be as low as 0.5 days (for example, a single event lasting one day and impacting half of PSE&G's customers, or two events each lasting one day and each impacting one-quarter of PSE&G's customers) if we adopted the VOLL per unserved kWhs for commercial customers as reported in the Berkeley study. Applying that assumption produces benefits to electric customers over the course of a three day outage equal to nearly $12 billion (and over $17 billion on a non-coincident basis). Likewise, applying lower VOLLs or lowering our estimates of the values that customers place on mitigating gas outages would result in increasing the break-even outage duration for the ES sub-programs.

Overall, we consider our estimate – *i.e.*, break-even outage durations of 3.08 days to cover Electric ES investments and 7.08 days to cover Gas ES – to be conservative. The break-even measures described above indicate that three single day outages – that is, at outage levels that fall between Hurricane Irene and Superstorm Sandy – over the life of the Electric ES assets would be sufficient for electric customers to realize value to pay for PSE&G's Electric ES investments. Using an actual example, PSE&G's Electric ES investments would have already been paid for if they had been in place in 2011, prior to the outages caused by Hurricane Irene, the October snowstorm and Superstorm Sandy.

Several multi-day outage events involving flooding that affects PSE&G's gas system over the life of the Gas ES assets would produce values to customers equal to or greater than the investment costs associated with PSE&G's Gas ES program costs, albeit with a higher break-even duration point than for PSE&G's Electric ES investments.

Break-even outage durations vary considerably across individual ES sub-programs. The sub-program investments that affect broader groupings of customers tend to have lower break-evens in terms of outage durations than do sub-program investments that are aimed at individual circuits and/or customers. This is primarily because investments in individual circuits or gas piping are "paid for" by fewer customers; more outage hours by a relatively few customers are needed to cover the PV of the investments aimed at individual circuits and/or customers.

I. INTRODUCTION AND OVERVIEW

PSE&G requested that *The Brattle Group* review the company's Energy Strong (ES) proposal submitted to the New Jersey BPU in February 2013, and estimate the benefit potential that may be realized from these investments. This chapter provides a brief overview of PSE&G's electric and gas operations and its recent proposal to make its energy delivery system "harder" and more resilient through the ES program. The chapter also provides the framework which we use to assess the program's benefit potential.

A. PSE&G ELECTRIC AND GAS OPERATIONS

PSE&G is a combined utility that provides electric and gas services to nearly 2.5 million customers, as is summarized in **Table I-1**. Roughly 1.4 million PSE&G customers receive combined electric and gas services.

Table I-1
PSE&G Electric and Gas Customers
2012

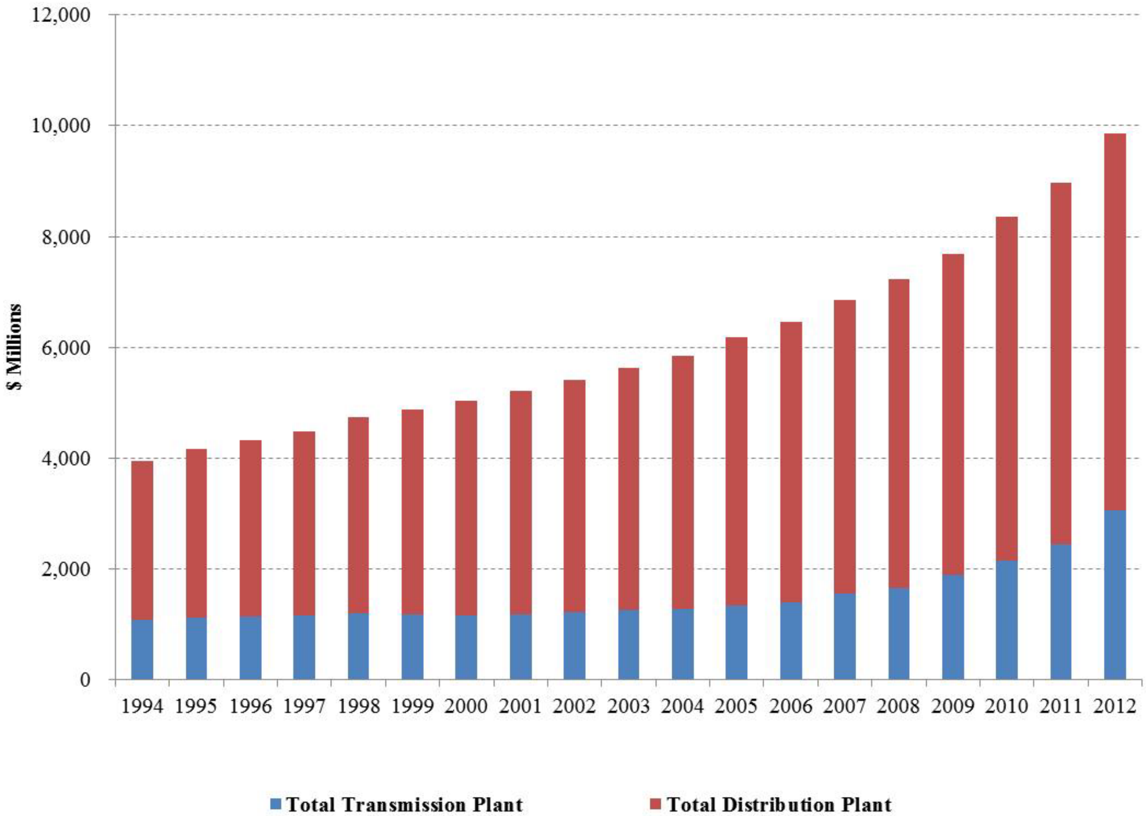
	Electric Only Customers	Gas Only Customers	Gas and Electric Customers	Total Customers
Residential	557,535	294,301	1,314,165	2,166,001
Commercial	165,260	42,300	108,239	315,799
Industrial	4,752	2,383	4,467	11,602
	727,546	338,984	1,426,872	2,493,402

Sources and Notes: 2012 FERC Form 1 and PSE&G data.

PSE&G delivers electricity to approximately 2.2 million meters in an area covering roughly 1,400 square miles.[1] The company owns and operates electric delivery assets which had a gross book value of roughly $9.9 billion as of year-end 2012, as is shown in **Figure I-1**.

[1] PSE&G serves 2,154,418 customers (based on its FERC Form 1 filed in 2013 covering operations ending in 2012). Many electric customers are served by multiple meters. The total number of meters served by PSE&G is 2,233,907 (as shown in the company's *Electric Delivery Distribution Performance Report Review through December 31, 2012*, dated January 11, 2013.)

Figure I-1
PSE&G Electric Transmission and Distribution
Plant In Service
($ Millions)



Source: FERC Form 1s filed by PSE&G. Distribution plant in service includes the year-end balances for FERC Uniform System of Accounts (USOA) accounts 360 – 374. Transmission plant in service includes the year end balances for USIA accounts 350 – 359.

Notes: Annual plant in service is the year-end balances recorded by PSE&G and shown in each year's FERC Form 1. Plant in service reflects the original cost less depreciation (OCLD) plus/minus transfers and adjustments.

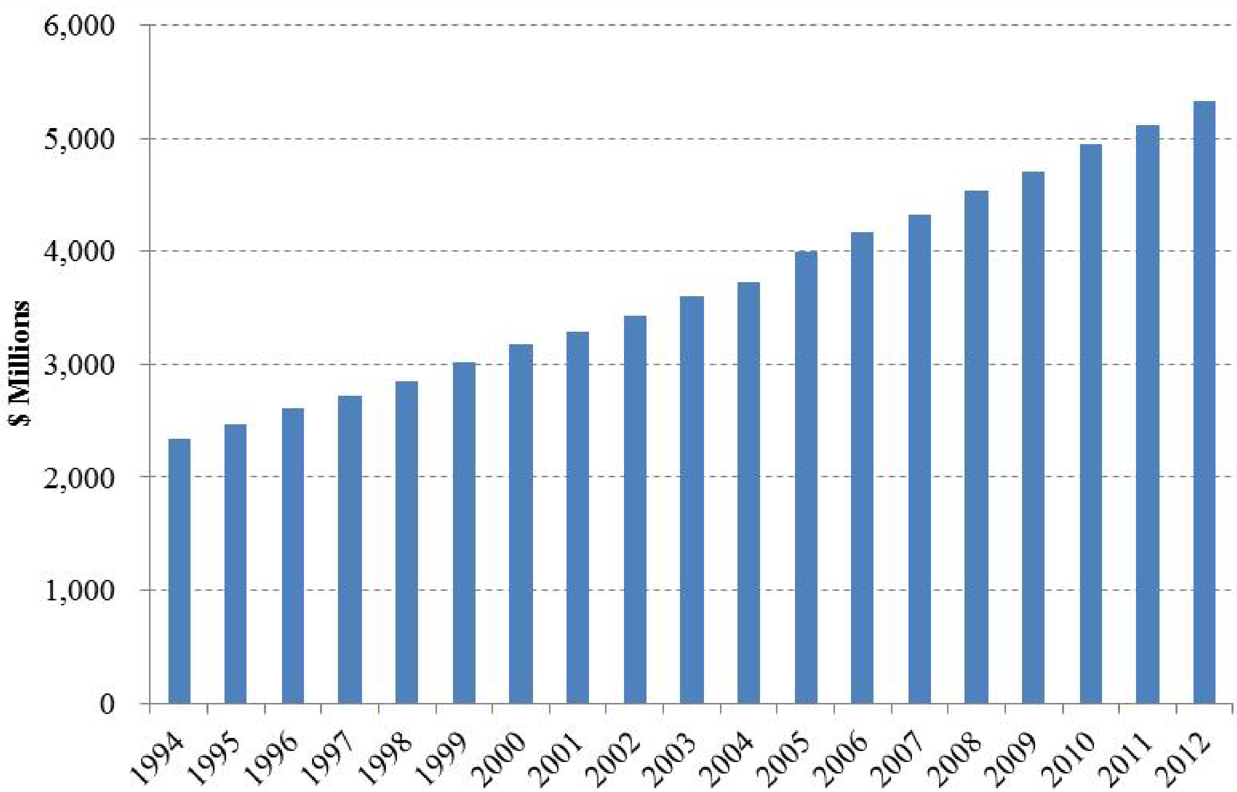
PSE&G routinely re-invests in its distribution systems each year. The gross book value of its total transmission and distribution plant has increased by 5.8% per year since 2000.[2] The majority of these investments have been in its distribution plant. The gross book value of PSE&G electric distribution plant in service is $6.8 billion, and has grown by 4.8% per year

[2] Gross book value equals the year end transmission and distribution electric plant in service as reported in PSE&G's FERC Form 1s; it is equal to original cost plus/minus transfers and adjustments.

since 2000, while the gross book value of the company's transmission plant in service is $3.1 billion, and has grown by 8.4% per year since 2000.

PSE&G also delivers natural gas to almost 1.8 million customers in New Jersey. The company owns and operates gas delivery assets with a gross book value of roughly $5.3 billion as of year-end 2012, as is shown in **Figure I-2**. The gross book value of PSE&G gas plant in service has increased by 4.4% per year since 2000.

Figure I-2
PSE&G Natural Gas Distribution
Plant In Service
($ Millions)



Source: FERC Form 1s filed by PSE&G. Distribution plant in service includes the year-end balances for FERC Uniform System of Accounts (USOA) accounts 360 – 374. Transmission plant in service includes the year end balances for USIA accounts 350 – 359.

Notes: Annual plant in service is the year-end balances recorded by PSE&G and shown in each year's FERC Form 1. Plant in service reflects the original cost less depreciation (OCLD) plus/minus transfers and adjustments.

B. ENERGY STRONG PROPOSAL

PSE&G's ongoing investment in its electric and gas delivery systems has been based on targeting industry standard or even industry leading levels of system reliability and safety. The company's proposed ES investment program is aimed at avoiding and/or reducing prolonged outages – *i.e.*, those caused by major weather events – in the PSE&G electric and gas systems by hardening PSE&G's infrastructure and enhancing system resiliency. Infrastructure hardening investments are generally concerned with mitigating flood and tidal storm surge and securing assets to withstand winds and extreme climate conditions. Enhancing system resiliency involves the incorporation of system intelligence and communications, primarily with respect to PSE&G's electric operations.

The proposed ES investment program is composed of 4 investment areas: 1) Electric Delivery Infrastructure Hardening Investments, which includes 6 sub-programs; 2) Electric Delivery Infrastructure Resiliency Investment, which includes two sub-programs (Advanced Technologies and Contingency Reconfigurations) covering a range of system and communications enhancements; 3) Supplemental (Electric) Investments, which includes 2 sub-programs; and 4) Gas Delivery Infrastructure Hardening Investments, which includes 2 sub-programs.

PSE&G's ES investments are proposed to be made over the next 10 years. A preliminary summary of PSE&G's ES investments is provided in **Table I-2.** A summary of PSE&G's ES investments on a present value (PV) basis is provided in **Appendix A**.

Table I-2
PSE&G Energy Strong Investments
Summary of Total and Investment Costs

Program	Sub-Program	Invest Areas	Description		Proposed Investment (2012$ millions): Investment: Months 1 - 60 $	%	Investment: Months 61 - 120 $	%	Total Investment $	%
Electric Delivery System										
Asset Hardening	1	1	Station Flood Mitigation		$819	20.8%	$859	21.8%	$1,678	42.6%
Asset Hardening	2	3	Enhance OP Construction Standards		$135	3.4%	$0	0.0%	$135	3.4%
Asset Hardening	3	1	Strengthening Pole Infrastructure		$105	2.7%	$0	0.0%	$105	2.7%
Asset Hardening	4	1	Rebuild/Relocate Backyard Poles		$100	2.5%	$0	0.0%	$100	2.5%
Asset Hardening	5	3	Undergrounding		$76	1.9%	$0	0.0%	$76	1.9%
Asset Hardening	6	1	Relocate Critical PSE&G Operating Centers		$15	0.4%	$0	0.0%	$15	0.4%
Total Asset Hardening		10			$1,250	31.7%	$859	21.8%	$2,109	53.5%
System Resiliency	1	1	Advanced Technologies - System Visibility	Micro Relays and SCADA eqpt	$120	3.0%	$130	3.3%	$250	6.3%
System Resiliency	1	1	Advanced Technologies - System Visibility	Distribution Management System	$24	0.6%	$26	0.7%	$50	1.3%
System Resiliency	1	1	Advanced Technologies - Comm Network	Fiber Optic Network	$35	0.9%	$38	1.0%	$73	1.9%
System Resiliency	1	1	Advanced Technologies - Comm Network	Satellite Comm	$3	0.1%	$0	0.0%	$3	0.1%
System Resiliency	1	1	Advanced Technologies - Storm Damage Assess	Advanced Distribution Management System	$9	0.2%	$6	0.2%	$15	0.4%
System Resiliency	1	1	Advanced Technologies - Storm Damage Assess	Enhanced Storm Management Systems	$50	1.3%	$0	0.0%	$50	1.3%
System Resiliency	1	1	Advanced Technologies - Storm Damage Assess	Expand Communications Channels	$10	0.3%	$0	0.0%	$10	0.3%
System Resiliency	2	1	Contingency Reconfiguration Strategies		$200	5.1%	$0	0.0%	$200	5.1%
Total System Resiliency		8			$451	11.4%	$200	5.1%	$651	16.5%
Supplemental	1	1	Emergency Backup Generator and Quick Connects		$2	0.1%	$0	0.0%	$2	0.1%
Supplemental	2	1	Muni Pilot Program		$0	0.0%	$0	0.0%	$0	0.0%
Total Supplemental		2			$2	0.1%	$0	0.0%	$2	0.1%
Total Electric Delivery System					$1,703	43.2%	$1,059	26.9%	$2,762	70.1%
Gas Delivery System										
Asset Hardening	1	1	Metering & Regulating Station Flood Mitigation		$76	1.9%	$64	1.6%	$140	3.6%
Asset Hardening	2	1	Utilization Pressure Cast Iron (UPCI)		$830	21.1%	$210	5.3%	$1,040	26.4%
Total Gas Delivery System					$906	23.0%	$274	7.0%	$1,180	29.9%
Total Energy Strong Investment					**$2,609**	**66.2%**	**$1,333**	**33.8%**	**$3,942**	**100.0%**

Sources and Notes: PSE&G Energy Strong Filings, BPU Docket Nos. EO13020155 and GO13020156.

As indicated in the table, the first phase (months 1 - 60) of ES investment in total (*i.e.*, covering both electric and gas investment) is approximately $2.6 billion in 2012 dollars, and has a PV of roughly $2.1 billion.[3] The program's second phase (months 61 – 120) in total is roughly $1.3 billion in 2012 dollars, with a PV of approximately $770 million. The total costs for the entire ES programs are approximately $3.9 billion. On a PV basis, this is equal to $2.9 billion.[4]

Electric Delivery ES. The first phase (months 1 - 60) of ES investment in PSE&G's electric delivery system is approximately $1.7 billion in 2012 dollars, and has a PV of roughly $1.4 billion. The program's second phase (months 61 – 120) is roughly $1.1 billion in 2012 dollars, with a PV of approximately $595 million. The total costs for the electric delivery programs are nearly $2.8 billion, for a PV of roughly $2 billion.

Gas Delivery ES. The first phase (months 1 - 60) of ES investment in PSE&G's natural gas delivery system is approximately $906 million in 2012 dollars, and has a PV of roughly $732 million. The program's second phase (months 61 – 120) is roughly $274 million in 2012 dollars, with a PV of approximately $174 million. The total costs for the gas delivery programs are nearly $1.2 billion, for a PV of roughly $907 million.

C. BENEFIT VALUE APPROACH

The stated purpose of PSE&G's proposed ES program investments is to harden and enhance the resilience of its electricity and natural gas service. Such investments benefit customers by reducing the likelihood that severe weather will cause electric or gas outages and/or by reducing the duration of outages should they occur. Specifically, asset hardening should reduce the number of customers who experience outages, and resiliency related investments should reduce the duration of outages for those customers who have their utility service interrupted. Thus, PSE&G's ES investments do not necessarily "pay for themselves" by, for example, reducing operating costs. Instead, the benefit associated with PSE&G's ES investments can be derived by

3 Assumes a discount rate of 7.01%, as used by PSE&G in its Energy Strong filings with the BPU.

4 Analysis herein includes the entire expected cost of the Energy Strong program (*i.e.*, months 1 – 120). However, in its Energy Strong proposal, PSE&G is requesting the BPU to approve the first five years of the program only.

estimating the number of hours of customer outages during major weather events that would be mitigated due to the ES investments, and in turn estimating the value that customers place upon avoiding hours of interruptions to their utility services as a result of those major weather events

We estimated the benefit potential to PSE&G's customers in two primary steps. First, we reviewed the specific ES electric and gas sub-programs, the customers that are targeted to be affected by each sub-program, and the impact (as estimated by PSE&G's engineers) that the sub-programs are likely to have on mitigating service interruptions stemming from major weather events. This provided an indication of the percentage of customer minutes of interruptions in a major weather event-related outage that may be avoided and/or reduced as a result of PSE&G's ES investments. Second, we reviewed economic research and developed analyses through which we estimated the value to customers of avoiding outages and/or experiencing outages of lesser duration. The product of the mitigated outage minutes and the value that customers place upon avoiding outages provides an estimate of the benefits that may be realized by customers from PSE&G's ES investments.

Estimates of the durations of outages that can be avoided and/or reduced are highly uncertain primarily because the ES program is targeted toward combatting the effects of severe weather events that may or may not occur. Thus, it is not possible to estimate the expected value of benefits associated with PSE&G's ES investments – calculated as the product of the value of avoided and/or reduced service interruptions times the change in the probability of such outages – without specifying the probabilities of severe weather events affecting PSE&G's customers in the future. These probabilities are not presently available.

Benefit-Cost Comparison. We estimated the benefits that may accrue to PSE&G's electric and gas customers using two approaches. First, we estimated benefits for the case under which the area was faced with a three day outage of its electric system and a five day outage of portions of its gas system. We based these levels of outage duration on a combination of recent experiences following major weather events, such as Hurricane Irene and Superstorm Sandy, and the projected impacts of flooding and/or storm surges on utility systems. Comparing the calculated benefits to investment costs provided an indication of benefit-cost. Such a point estimate of outage duration provides an informative illustration of the benefits and benefit-cost ratio that would likely accrue to customers under *specific* outage circumstances.

We also conducted a "break-even" analysis under which we estimated the cumulative duration of outages that would produce a level of value to customers equal to the cost of PSE&G's ES investment program. This break-even analysis provides an indication of the number and duration of outages associated with major weather events that would have to occur in order for PSE&G's ES investment to provide value to its customers sufficient to cover the investment cost.

Value To Customers. Customers place value upon receiving reliable utility services, and studies have been conducted to estimate the willingness of customers to pay to avoid outages. Multiple studies of the *value of lost load*, or VOLL, to electric customers have been conducted,[5] and we use these studies as the basis for estimating the value to PSE&G's electric customers of avoiding outages. These studies are not available for gas customers, and we apply other methods in estimating the value of avoiding outages for PSE&G's gas customers, specifically analysis concerning consumer surplus and value added.

Consumer surplus is a measure of the value (of electric or gas purchase) that can be estimated from one or more customers' demand curves for that service, and reflects consumers' willingness to pay more than the prevailing price for utility service. Such an estimate likely understates the true total value of a temporary loss of service because measurement of customer demand curves excludes un-measurable and/or intangible values. We used consumer surplus analysis to estimate the value to residential gas customers of avoiding the loss of gas service.[6]

Value added analysis is relevant to estimating the value of utility service for commercial and industrial (C&I) customers. This method examines the lower and upper bounds of customer profitability, and is based on the assumption that the value to a C&I customer of avoiding the loss of electric and/or gas service for, say, a day, cannot exceed the margin or profit that the

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[5] Importantly, these methods of estimation reflect only the private value of avoiding service interruptions and do not include wider ranging social benefits.

[6] Another element of value gained is the producer surplus earned by utility suppliers and distributors. In general, producer surplus is equivalent to the profits each vendor along the supply chain earns when energy is supplied to PSE&G customers. We do not estimate producer surplus in our analysis.

customer would realize if it was under normal operations for that day. For example, if a retail store earns $100 a day in profits, and it cannot operate without power and/or gas, it would be willing to pay up to (and not more than) $100 per day to maintain its utility service. This $100 per day is a reliable order of magnitude upper bound of the value of lost service. However, it is unlikely that a customer would be willing to pay this level because other factors come into play, such as the customer's ability to defer some sales or other activities.

The three methods above provide an estimate of the value to customers of avoiding 1) the loss of electric service as part of a prolonged outage, and 2) the loss of gas service as part of a prolonged outage. We consider an outage to be prolonged when its duration is equal to or greater than eight hours. We then compare the values of avoiding a loss of electric and gas service estimated under the VOLL, consumer surplus and value added estimate methods, and adjust the values applicable to residential, commercial and industrial customers in order to ensure that the values of losing utility service is consistently applied.

Additional Benefits. PSE&G's ES investments will likely provide additional benefits, including improved electric and gas system reliability under more normal weather conditions and reduced O&M[7] and/or restoration costs.[8] The Gas ES program will also provide customers with increased conveniences to customers, notably with respect to their ability to use higher-efficiency gas appliances.

As indicated, the primary focus of our analysis has been the value PSE&G's customers place, as individuals, on the reliability improvements offered by Energy Strong. However, there are broader benefits that are realized by the community at large when the number and duration of severe weather outages are reduced. These include public safety benefits (including lower first

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7 A notable example is the ES sub-program to upgrade a portion of the cast iron gas distribution system operating at "utilization pressure" (UPCI). This program will result in reduced O&M costs, because older pipe will be replaced with newer materials which in turn results in reduced need for repairs. It also results in reduced leakage of gas, which reduces the ultimate cost of gas service to customers.

8 For example, more hardened gas assets may have allowed PSE&G to avoid spending over $400,000 spent to repair flooded M&R stations. (RCR-G-POL-38)

responder costs), and environmental benefits associated with reduced leaks in the gas system.[9] PSE&G's ES program will also mitigate the macroeconomic losses that typically follow severe weather events.

A macroeconomic analysis conducted by the Edward J. Bloustein School of Planning and Public Policy at Rutgers University quantified the economic impact of Superstorm Sandy on the State of New Jersey.[10] The study found that Superstorm Sandy was responsible for very substantial economic losses in New Jersey, estimated to be approximately $12 billion in lost economic output in 2012 alone, as well as reduced levels of tax revenues and jobs.[11] The study also found that economic losses will continue throughout the four year study period unless the State receives repair and recovery funds.

Overall, the Rutgers Study estimated that Superstorm Sandy caused a reduction of $82.2 million in tax revenues in 2012, with sales, gas, and alcohol taxes declining immediately after the storm.[12] State tax collections are also highly sensitive to bonuses, dividends, and capital gains, and many of these are likely to have been adversely affected by the storm.[13] The impact on government operations were further impacted by the repair and restoration costs imposed on

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[9] Upgrading a portion of the cast iron gas distribution operating system also results in reduced natural gas leakage (*i.e.*, from newer pipes with greater structural integrity). Methane is recognized as a potent greenhouse gas, and thus more efficient piping reduces the environmental impact of the gas distribution system.

[10] Mantell, Nancy, Joseph J. Seneca, Michael L. Lahr, Will Irving, "The Economic and Fiscal Impact of Hurricane Sandy in New Jersey." Rutgers Regional Report, Number 34, January 2013. (Rutgers Study). The study noted that some of these impacts would be mitigated if the State received repair and recovery funding.

[11] The study assumed that the State immediately lost two-thirds of its total economic activity for a full week during and just after the storm, or about $5.56 billion, as well as $2.78 billion and $1.39 billion during the following two weeks, respectively.

[12] Rutgers Study, p. 5.

[13] Rutgers Study, p. 11. Some businesses such as construction may experience a net positive impact from the storm, with corresponding positive impacts on owners' incomes and tax payments. However, the overall impact to the State economy is positive only in the event that full reconstruction funding is realized, as emphasized on p.10 of the study, and even then the gains will occur in subsequent years while the losses are immediate.

State and local governments, which are estimated to be more than $8 billion for parks and water systems alone.[14]

Superstorm Sandy also triggered the immediate loss of about 4,200 jobs. Unemployment compensation claims increased by about 100,000 immediately following the storm; fortunately, most of these claims were associated with temporary storm-related unemployment. The study also estimated that personal income in New Jersey fell by over $1 billion in the fourth quarter of 2012.

PSE&G's ES program would have a definite impact on mitigating some of the negative macroeconomic impacts from Superstorm Sandy, although that impact cannot be estimated precisely without significant additional study. However, it is clear that investments that reduce the scope and duration of prolonged power and gas outages will also reduce near-term losses in economic activity and jobs.

PSE&G's ES program will also create an average of 5,325 FTEs per year[15]. This is a sizable number in itself, but also comparable to the jobs that the Rutgers study estimated may need to be created in order to repair and restore the utility infrastructure in New Jersey that was damaged by Superstorm Sandy. The Rutgers study estimated that all New Jersey electric and gas utilities will spend a total of about $1.8 billion for repair and restoration, but not necessarily upgrade, of their infrastructure between the end of 2012 and the first quarter of 2014. The State would be much better served by the jobs created by PSE&G's ES program. These involve upgrading the State's utility infrastructure and also aid in preventing part of the macroeconomic losses that inevitably result from severe weather events.

These additional areas of benefits are important and material, but they are not quantified as part of our analysis. A full assessment of the benefits of the ES program (or any other utility investment program) should quantitatively or qualitatively factor these into account.

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14 Rutgers Study, p. 14.

15 Direct Testimony of Jorge L. Cardenas, 42:955-957; Response to S-PSEG-ES-53 and RCR-ECON-3.

D. ORGANIZATION OF REPORT

The organization of this report follows from the benefit framework described above. First, we develop estimates for the values to customers for avoiding the loss of electric and gas services. We then review PSE&G's ES sub-programs and determine the loss of service that can be avoided and/or reduced as a result of such investments. Finally, we estimate the break-even outages that would need to be realized in order to "pay for" PSE&G's electric and gas ES investments.

The remainder of this report is organized as follows:

- In Chapter II, we discuss the three methods used to estimate the values to customers of avoiding outages of electricity and natural gas delivery, reconcile across methods and, lastly, provide a consistent set of values to customers of avoiding outages that will be used in calculating the benefits associated with PSE&G's ES program.

- Chapter III provides the detailed estimate of the value of avoiding outages to electric customers, and estimates the break-even outage duration needed to pay for PSE&G's ES electric delivery investments.

- Chapter IV provides a similar analysis for the company's ES gas delivery investments. Specifically, the value of avoiding outages to gas customers and an estimate of the break-even outage duration is provided.

- Chapter V includes a sensitivity analysis and our conclusions concerning the benefit potential for PSE&G's ES investment program. Benefits are provided for electric delivery and gas delivery investments on a stand-alone basis, and the combined effects of the two.

II. ESTIMATING THE VALUE TO CUSTOMERS OF AVOIDING AND/OR REDUCING SERVICE OUTAGES

It is well established in economics that the prices that utility customers pay for their power, gas, and other similar products does not measure the full value that these customers derive from reliable utility service. The value derived from these essential services, or what customers would be *willing to pay*, is typically much, much higher than the regulated prices they do pay. The full value of utility service is one of several useful inputs for determining the optimal level of utility investment and for many other planning exercises, including planning enhanced resilience programs such as Energy Strong.

The value of utility service to customers has been estimated by electric utilities using a Willingness-To-Pay (WTP) and/or the Value of Lost Load (VOLL) methodology. Such studies have been less available for gas customers. However, the value of avoiding gas outages can be estimated by 1) analyzing consumer surplus, which we apply to PSE&G's residential gas customers, and 2) value added analysis, which we use in estimating the value of avoiding outages for PSE&G commercial and industrial gas customers.

This chapter summarizes the analysis conducted to estimate these three areas of customer value. We then compare the values of avoiding outages and adjust as needed to ensure that the value methodologies are consistently applied in our analysis of benefits associated with PSE&G's ES programs.

A. VALUE OF LOST LOAD (VOLL)

Estimating the VOLL is largely a survey-based process through which utility customers value the economic impacts that varying levels of outages have upon their households and/or businesses. Accordingly, VOLLs need to be estimated separately for the various customer classes, because the impact of an outage can differ significantly among residential customers (who are inconvenienced by an outage and, if the outage duration is long enough, will incur out-of-pocket costs) and commercial and industrial customers (for which a loss of power will likely have an impact on production processes, result in a loss of sales and revenue and/or involve out-of-pocket costs). The accuracy of the VOLL estimate depends upon the quality of the survey methodology, instrument and procedure. Thus, estimates of VOLLs are an informative but non-perfect measure of service value.

Estimating and incorporating VOLLs into utility planning remains an evolving process; some, but by no means all or even most, utilities have estimated VOLLs for their specific customer base. However, industry research has been developed in this area based largely upon the efforts of individual utilities throughout the country. A widely accepted study on VOLL was reported by the Lawrence Berkeley National Laboratory.[16] The Berkeley study compiled the results of 28 VOLL studies conducted by electric utilities into a single data set and then estimated VOLLs based on a customer damage function (CDF). Specifically, a two-part multiple regression analysis is performed to estimate the VOLL for three classes of customers for various durations of outages: residential customers; small commercial and industrial customers; and medium and large commercial and industrial electric customers.[17]

PSE&G has not conducted VOLL studies for its specific customer base. However, the results from the Berkeley study should be generally applicable to customers in New Jersey. The Berkeley CDF and VOLL estimates were based on a wide range of customers and geographic areas, although observations for the northeast and mid-Atlantic states (including New Jersey) were absent.[18] New Jersey has higher levels of income and economic activity than much of the

[16] Sullivan, M., Mercurio, M., and Schellenberg, J. (2009) *Estimated Value of Service Reliability for Electric Utility Customers in the United States,* Lawrence Berkeley National Laboratory. The Berkeley study used research and results from 28 customer value of service reliability studies conducted by 10 major US electric utilities over the 16 year period from 1989 to 2005.

[17] Multiple regression analysis uses an ordinary least squares (OLS) approach to estimate parameters. However, in the meta-data set compiled for the Berkeley study, many respondents (customers) provided "zero" values (economic impact) for short duration power outages. This issue (data bounded by zero and having long "tail" in the upper end of the distribution) was addressed by using a two part regression. The first part predicts the probabilities that these zero values are correct (and not errors or omissions). The second part estimates interruption costs (VOLLs) for positive responses only, and then relates them to independent variables (such as customer classes). The two parts are then combined to the ultimate VOLL predictions. From: *Estimated Value of Service Reliability for Electric Utility Customers in the United States,* Lawrence Berkley National Laboratory.

[18] The results and full details of the 28 studies that populated the Berkeley meta-data set are confidential and not available for review and inspection. However, the Berkeley study indicates that the underlying VOLL studies, which were combinable because all followed similar survey practices, covered 11,970 firms (*i.e.,* commercial and/or industrial customers) and 7,693 households (*i.e.,* residential customers). Utilities that provided data included: Bonneville Power Administration, Cinergy (now Duke Energy), Duke Energy,

geographic areas covered by the Berkeley study.[19] Thus the VOLLs estimated by this study are generally applicable, or even conservatively low, for PSE&G's customer base.

VOLLs are estimated for ranges of outage durations; that is, separate VOLLs are estimated for each customer class for momentary outages (or voltage sags), outages of a single hour in duration, and outages spanning durations ranging from a two hour outage through a 12 hour outage. VOLLs are expressed in terms of: 1) the total dollar of economic impact associated with the outage duration; and 2) the dollar value per kWh unserved due to the outage.[20] As displayed in **Figure II-1** and **Figure II-2**, the total dollar values to customers of avoiding outages increase as outage durations increase, but the inverse is case with respect to the dollar VOLL per unserved kWh. For longer outage durations, a higher total dollar VOLL is spread over more kWhs, meaning that the VOLL expressed on a per unserved kWh basis is lower for longer duration outages than for shorter duration outages.[21]

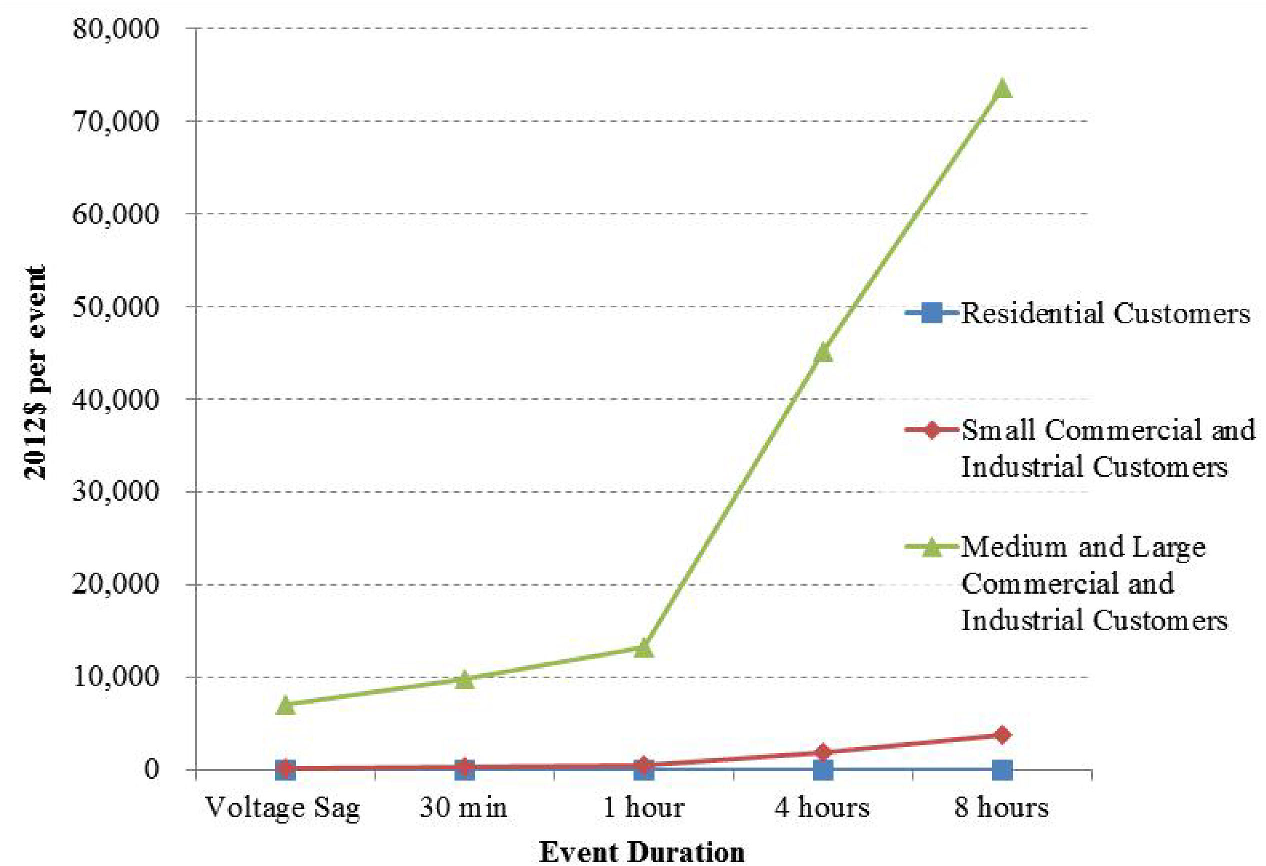
Mid America Power, Pacific Gas and Electric, Puget Sound Energy, Salt River Project, Southern California Edison, and Southern Company. This covered "virtually all the Southeast, most of the western U.S. (including almost all of California, rural Washington and Oregon, and the largest metropolitan areas in Arizona and Washington), and the Midwest south of Chicago." It did not specifically cover the northeast and mid-Atlantic region (which includes New Jersey).

19 The Bureau of Economic Analysis (under the U.S. Department of Commerce) provides statistics and rankings by state concerning income and gross domestic product (GDP). New Jersey had the 8th highest state GDP in 2012 and the 4th highest per capita personal income (behind DC, Connecticut, and Massachusetts). The states included in the Berkeley study all had average per capita personal incomes lower than New Jersey and only California had an average state GDP that was higher than New Jersey.

20 VOLLs can also be expressed in terms of kWs and the dollar per annual kWhs consumed. Conversion of the dollar economic impact into per unit VOLLs (dollar per unserved kWh, per kW, and per annual kWh consumed) require assumptions concerning customer load factors and other considerations.

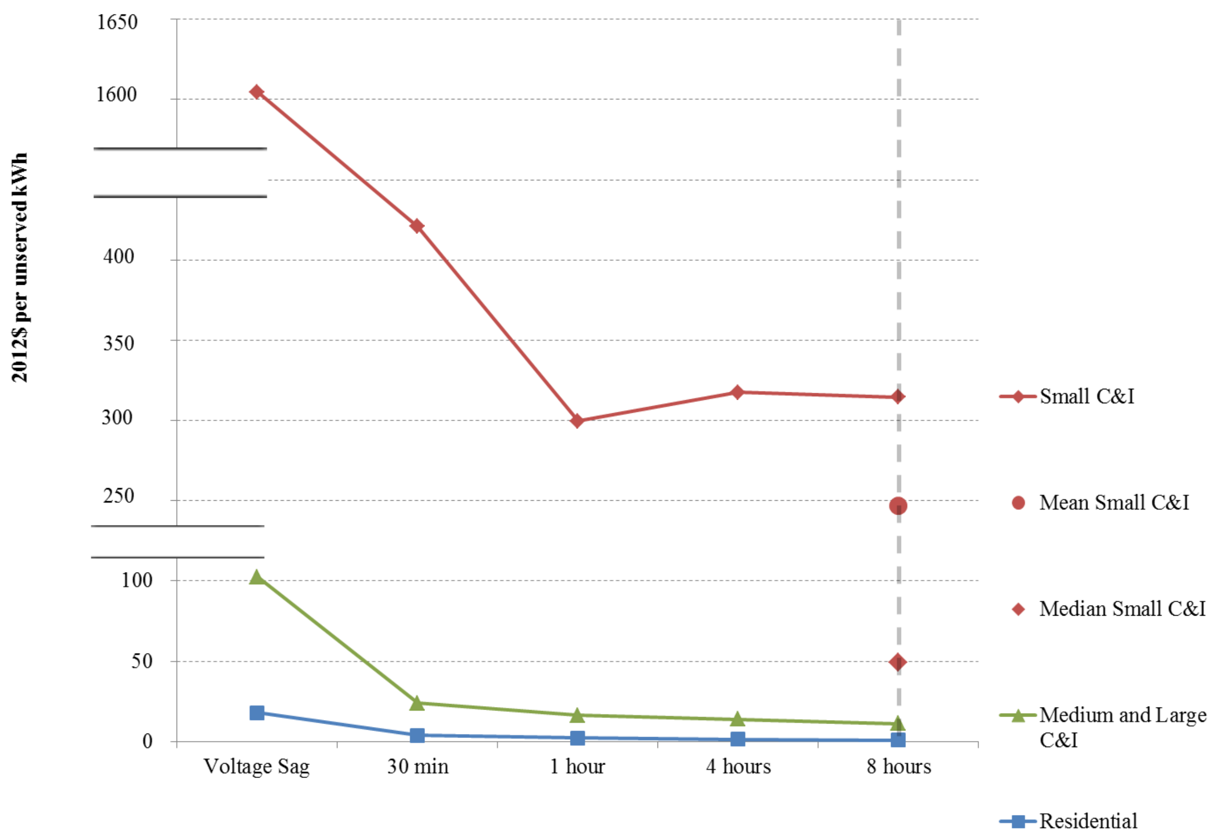
21 Studies concerning VOLLs for very long duration outages have not yet been conducted to our knowledge. It is possible that this relationship (between total dollar VOLL and VOLL per unserved kWh) will not be accurate for very long outages; additional empirical study is required.

Figure II-1
Value of Lost Load – Dollar Impact Per Duration of Event
By Customer Class



Sources and Notes: Sullivan, M., Mercurio, M., and Schellenberg, J. (2009) *Estimated Value of Service Reliability for Electric Utility Customers in the United States.* Lawrence Berkley National Laboratory.

Figure II-2
Value of Lost Load – Per Unserved kWh
By Customer Class



Source: Sullivan, M., Mercurio, M., and Schellenberg, J. (2009) *Estimated Value of Service Reliability for Electric Utility Customers in the United States.* Lawrence Berkley National Laboratory, Table ES-5 (adjusted to 2012$).

Note: Predicted, mean and median values are shown for eight hour outage duration for small commercial and industrial customers.

The VOLLs for the lengthiest outage durations estimated are $0.92 per unserved kWh for residential customers and $11.29 per unserved kWh for medium and large commercial and industrial customers. These represent the values to customers of avoiding the loss of power – that is, estimates of the economic damages that they would incur as a result of a power outage lasting 8 hours. Of course, these values are not the cost basis to the electric utility, nor are they the price that an electric utility would charge its customers.

Perhaps most notable in the figure is the VOLL estimated for small commercial and industrial customers. The VOLL predicted by the regression analysis for this customer class is roughly $315 per unserved kWh for an 8 hour outage, which appears to be a very high value. The VOLLs for residential customers are understandably less than the comparable VOLLs for commercial and industrial customers because economic impact to households is largely shaped by limited losses of valued services, such as the costs of spoiled foods. The VOLLs for small commercial and industrial customers are likely higher than the comparable VOLLs for medium and large commercial and industrial customers because larger customers may be able to shift production schedules and/or switch to back-up generation (or their use of co-generation), which would lessen the economic impact of being without grid power. We found that the relatively high predicted VOLLs for small commercial and industrial customers included in the Berkeley study merited additional focus.

After reviewing the data underlying the VOLLs for small commercial and industrial customers included in the Berkeley study, we opted to use the median value for this customer class ($49.17 per unserved kWh) as representative of the VOLL for small commercial and industrial customers rather than the average and predicted values. The median value is considerably lower than the average; we consider this conservatism to be appropriate for a study of this nature.[22]

The VOLLs estimated in the Berkeley study reflect outage durations of up to 8 hours, which are short in comparison to recent prolonged outages in New Jersey. In PSE&G's service area and in other areas in the mid-Atlantic and northeastern regions, some customers were out of power for weeks following Superstorm Sandy; the average outage duration (*i.e.,* CAIDI) for PSE&G customers was roughly 3.5 days. To our knowledge, there is no empirically-based analysis that estimates the VOLLs for outages of this duration. We speculate that the downward curve of

[22] **Figure II 2** also shows the mean and median VOLL values (based on the survey data) for the small commercial and industrial class. These values are significantly less than the VOLLs predicted by the two stage regression (which is different than the relative values of predicted, mean and median for the residential and medium and large commercial and industrial customer classes). This is most likely because a few responses (*i.e.*, individual estimates of economic impact) were comparatively much higher than most, causing the two stage regression to provide much higher estimates than if these outliers were omitted. A comparison of the VOLLs predicted by the two stage regression and mean and median values for the three customer classes are included in **Appendix B**.

VOLL per kWh (observed for outage durations of up to 8 hours in the Berkeley study) would either stabilize or begin to increase, because the economic impacts to residential, commercial and industrial customers would become increasingly substantial. Also, as noted above, the VOLLs estimated in the Berkeley study do not include or incorporate the societal benefits (such as public safety and access to basic services) that are affected by prolonged power outages. Incorporating these lost benefits would also serve to increase the dollar per unserved kWh VOLLs when outage durations exceed 24 or 48 hours.

We use the dollar per unserved kWh VOLLs for 8 hour outages as a proxy for outages of much longer durations, which we believe provides a very conservative measure of their actual value.

B. Consumer Surplus

The VOLL equivalent for PSE&G's residential customers for natural gas service was approximated by estimating the consumer surplus associated with the demand curve of the average customer. Consumer surplus is the difference between a transaction price that actually occurred and the maximum price that the consumer would have been prepared to pay. Thus, analysis of consumer surplus provides an indication of customer willingness to pay, similar to the measures estimated in the VOLL analysis that was applied to electric customers.

Residential gas customer willingness to pay was estimated in four steps: 1) the average price paid for and quantity consumed of natural gas by PSE&G's residential customers was determined; 2) after consulting PSE&G and the relevant economic literature, a price elasticity was assumed for linear and constant elasticity demand curves; 3) price limits were estimated (specifically with respect to constant elasticity demand curves); and, 4) consumer surplus was estimated.

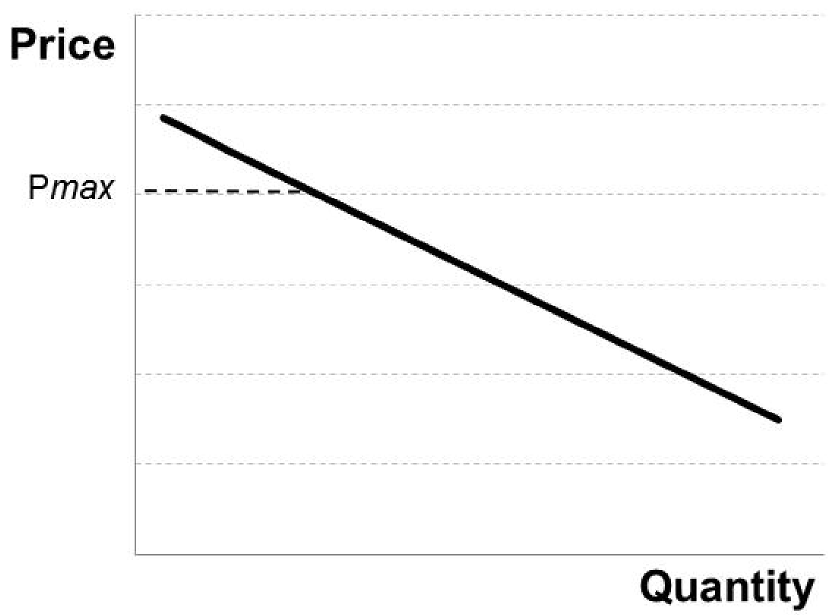
1. Demand Curves

Microeconomic theory is based on the concept that the value one customer places on buying a product can be expressed as a demand curve, or a curve showing the amount of one product a customer will buy as the price of that product varies. For virtually every good or service, including utility services, it is accepted that a demand curve may be characterized by three key features:

- There is a maximum price above which a consumer will not buy any of the product;
- There is a maximum quantity of the product a consumer will buy even if the price gets to be zero; and
- Between these two prices, the quantity demanded declines as price increases.

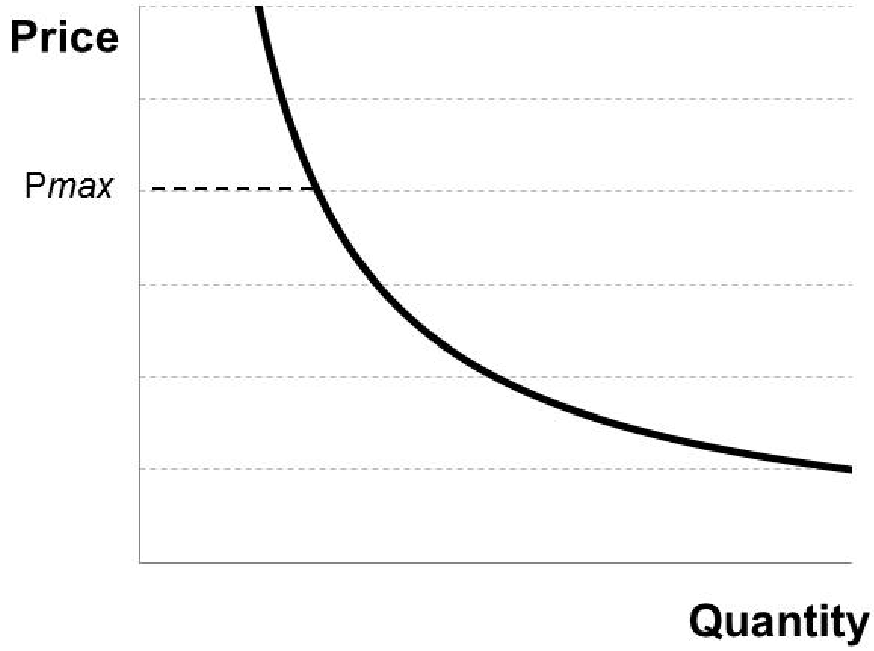
Putting these three elements together, a demand curve is traditionally drawn as shown in **Figure II-3**. In the figure, P*max* is the highest price a customer will pay for the product. Demand curves are frequently displayed as straight lines but they can also be represented as exponential functions, as represented in **Figure II-4**.

Figure II-3
Linear Demand Curve
Illustrative



Source: *The Brattle Group* © 2013.

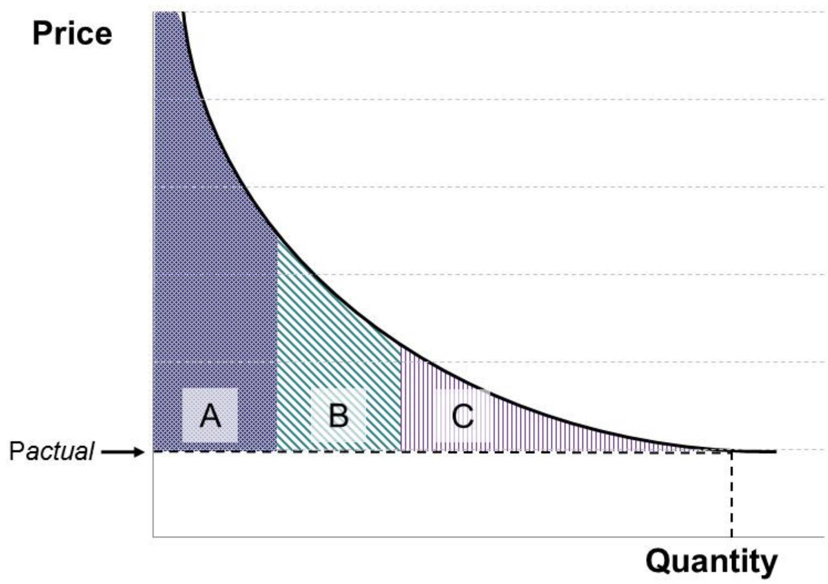
Figure II-4
Generalized Constant Elasticity Demand Curve



Source: *The Brattle Group* © 2013.

The economic reasoning underlying a demand curve is based on the concept of diminishing marginal utility, which indicates that the highest portion of the demand curve are the quantities of product that are devoted to the highest-value (most important) use of the product. This can be applied to utility provision of natural gas to residential customers. In most cases the highest value use of the product would be for space heating demands in the winter months, which is generally considered to be the most difficult to substitute. This portion of the demand curve is represented by Region A in **Figure II-5**. Region B on the figure represents the price that a customer will pay for the moderately important, but not the most essential uses, of the product (*e.g.*, cooking and hot water), and Region C on the figure represents the value placed on the least essential gas uses (such as gas barbeques or decorative fireplaces).

Figure II-5
Generalized Demand Curve
Residential Natural Gas Customers
During Heating Season



Source: *The Brattle Group* © 2013.

In this example, assume that the lower region of the demand curve (*i.e.,* Region C) provides the basis for the actual price being paid by residential gas customers, shown as P*actual* on **Figure II-5**. The consumer surplus, then, is equal to the area under the demand curve that is above the market (or tariff) price, as is represented by the shaded area ABC in the figure.

Demand curves also have a time dimension. A *short-run* demand curve reflects the capital goods (house, car, appliances) that customer has at the time of measurement, while a *long term* demand curve is estimated over a period during which the customer can make a decision to change their mix of capital goods (*e.g.* buy a new gas stove, or switch from oil-fired to gas-fired space heating).

This report focuses entirely on the value customers place on sudden disruptions in their gas service from rare and uncertain events. The period between when the event occurs (or is forecast to occur) and service is lost is too short to allow for changes in gas-using capital equipment. As a result, the short-run demand curve is the curve we use to value unexpected gas interruptions; the remainder of this analysis looks only at short-run demand.

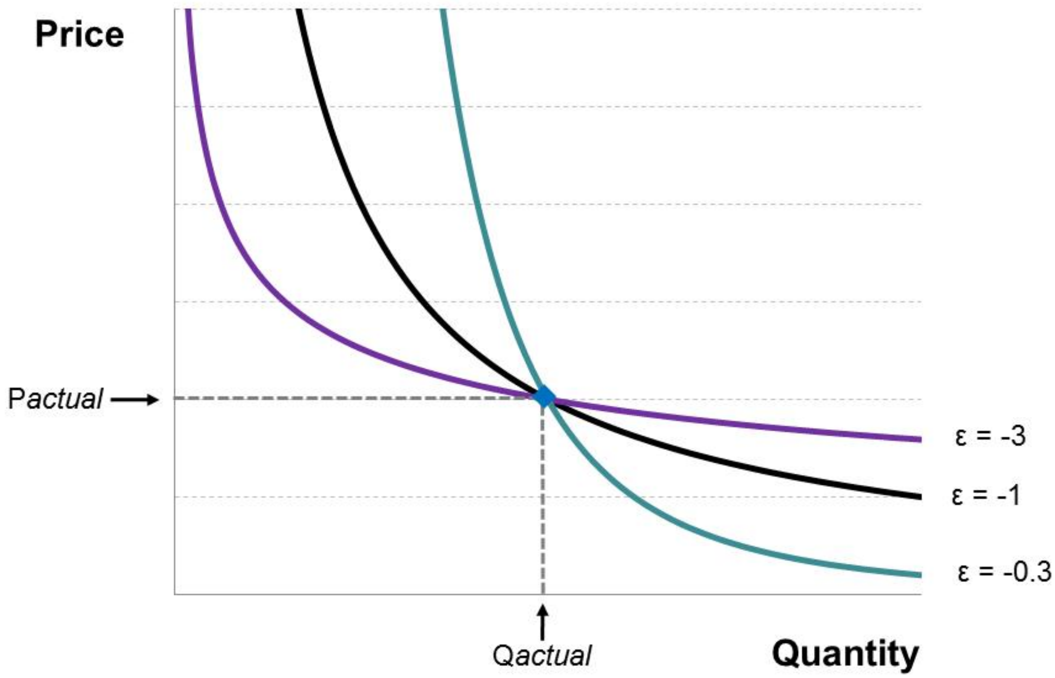
2. Demand Curve: Location and Shape

Ideally, demand curves for natural gas would be measured by changing the price charged to a customer from the actual price paid (P*actual* on **Figure II-5**) to P*max* and seeing how much gas that customer bought at each price. Of course, this is not possible in practice, and the shape and location of the demand curve must be estimated using economic techniques and assumptions.

A single point on the curve equal to the current (average) price the customer is paying and the quantity of gas that customer is using at that price (P*actual*, Q*actual*) can be observed with some certainty. The shape of the demand curve then follows its assumed functional form, the most common of which are either 1) linear (*i.e.,* a constant slope) or 2) an exponential curve, which is characterized by a constant price elasticity of demand. Price elasticity (hereafter simply referred to as elasticity) is a measure of price responsiveness equal to the ratio of the percentage change in quantity demanded to the percentage change in price paid.[23] For example, an elasticity of -1 indicates that the quantity purchased declines by 1% for every 1% increase in price. A linear (*i.e.,* straight line) demand curve can be developed by assuming that the slope of the demand curve stays the same as is dictated by the elasticity measured at P*actual*, Q*actual*. An exponential demand curve, as is illustrated in **Figure II-6,** is developed by assuming that every point on the demand curve has the same elasticity (ε).

[23] Strictly speaking, income and all other prices are held constant when price elasticity of demand is measured. For this reason, the price elasticity is sometimes referred to as the *own price* elasticity.

Figure II-6
Constant Elasticity of Demand

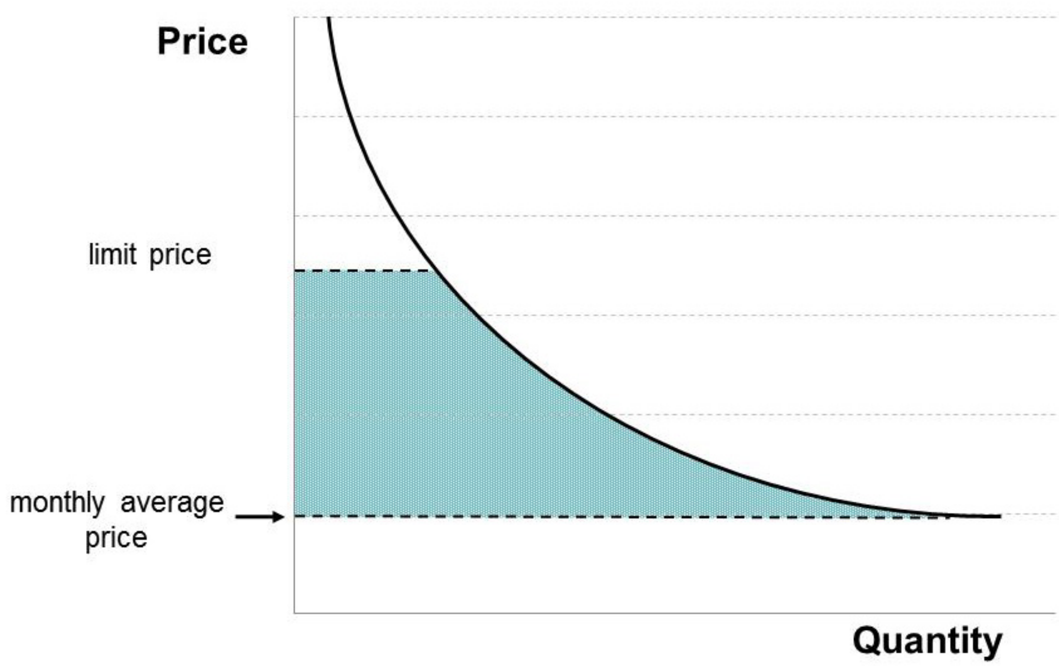


Source: *The Brattle Group* © 2013.

Determining the consumer surplus (for a given demand function) also requires incorporating practical considerations. Constant-elasticity demand curves are asymptotic (*i.e.,* the prices reflected in the demand curve are not high enough to make demand drop to zero) which suggests that the P*max* is not necessarily realistic. Thus, it is appropriate to limit the range of a constant-elasticity demand curve to regions of realistic price and value. This also comports with economic common sense.

The mathematical form of a constant-elasticity curve shows that a residential gas customer would theoretically continue to pay higher and higher prices for smaller and smaller amounts of gas, with no absolute limit. However, in practice, such behavior is quite unrealistic; in all likelihood, there is a price above which a residential gas customer would opt to discontinue gas service, even in the short run. For example, imagine that a home was run on propane fuel that had no price controls during a progressively more severe and prolonged propane shortage. At some point, a propane-powered homeowner would probably decide to shut down their home, drain the water pipes (if necessary), and move temporarily, perhaps to a motel not served by propane. Such a high price is referred to as the "limit price," above which consumer surplus should not be counted. Thus, consumer surplus is more realistically reflected as the area under the demand curve where prices exceed the market (or tariff) price but is lower than the limit price. This is illustrated by the shaded area in **Figure II-7**.

Figure II-7
Constant Elasticity with Limit Price



Source: *The Brattle Group* © 2013.

Although we have referred to the maximum price a customer will pay as the limit price, the maximum amount a consumer will pay for gas before foregoing gas service entirely can also be expressed as an aggregate maximum cost. In other words, for any one customer, the highest total cost they will pay for one day's gas service is the quantity of gas they will consume (when the price for gas is set equal to the limit price) multiplied by the limit price. We refer to this cost figure as the *limit cost* and use it rather than the limit price in our calculations below.

3. Estimated Consumer Surplus

We estimated the demand curve for PSE&G's residential gas customers by starting with the actual price and quantity demanded by the average residential customers, and then applying an estimate of elasticity to create linear and constant-elasticity demand curves. We assume a constant-elasticity functional form for the demand curve. The area under these curves (within prescribed limits) provides a conservative estimate of the average per-customer private value of PSE&G gas service.

Average Price and Quantity. In 2011, PSE&G's residential gas customers paid roughly $11.21 per MMBtu and consumed approximately 131 million MMBtu of natural gas. This *Price, Quantity* pairing became the starting point for estimating a demand curve for the average residential customer.

Price Elasticity. Utilities and independent researchers typically are able to estimate reliable measures of the elasticity of demand around current Price, Quantity pairings, and PSE&G routinely estimates the *long-run* price elasticity of demand for residential gas service in its service area. Previous price elasticity estimates were near -0.3; most recently, the same quantity was measured at -0.06.[24] The company's current estimate of price elasticity for the residential market appears low (in absolute terms) by historic standards, but is likely accurate reflecting the prolonged recession and an unusually large drop in natural gas prices during the recent expansion of shale gas supplies. It is also consistent with a study on this issue published by the U.S. Association of Energy Economics (USAEE), which placed the short-run price elasticity estimate in the Mid-Atlantic at -0.1.[25]

We used a price elasticity of -0.1 in developing an average demand curve for the residential gas market. We found that PSE&G's 2008 estimate of *long run* price elasticities reflected abnormal market conditions. Furthermore, our analysis requires estimates of *short run* elasticities which are generally lower (in absolute terms) than long run elasticities. Finally, we find the use of

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24 PSE&G 2013-2014 BGSS Commodity Charge Filing Forecast.

25 See Joutz, Frederick et al. "Estimating Regional Short-Run and Long-Run Price Elasticities of Residential Natural Gas Demand in the US," available at SSRN 1444927 (2009).

higher elasticities, in absolute value terms, to be conservative when applied to the current analysis.

Limit Price and Cost. As noted earlier, the limit cost is the highest daily total costs a household would realistically pay for gas service before declining gas service. We employ two distinct approaches to estimating this cost:

- *Within The Heating Season*. During the months of November through March, a daily decision to forego gas service – and the costs of doing so – would depend critically on the weather, the inconvenience of living without heat or the medical inability to do so, the risks and costs to the housing structure if there is no heat in it (or the cost of temporary electric heat, if electricity is available), the value of gas services other than heat during these months, and other factors. As an approximate bound on this, we employ a limit cost equal to half of the average temporary food and lodging costs for an average-sized New Jersey household (2.7 people). Using conservative estimates of New Jersey hotel room and meal costs from published sources and New Jersey state travel rules, we estimate an average limit cost of about $163 per family per day.[26]

- *Outside The Heating Season*. During the months of April through October, this is the daily cost at which it is no longer worthwhile having gas for water heating, cooking, and other uses. During these periods, we employ a limit price implied by a linear demand curve, a conservative curve shape relative to a constant-elasticity curve. Using the parameters referenced above, we estimate that residential consumers would not pay more than roughly $7-10 per day, on average across non-heating season months, for gas service.

A summary of the data and area constituting consumer surplus for PSE&G's residential gas customers is provided in **Table II-1**. As indicated in **Table II-1**, the total estimated consumer surplus of PSE&G residential gas customers is $31.4 billion. Dividing this by the number of customers and days in the year yields the average consumer surplus per PSE&G residential gas household per day (approximately $41) and the average consumer surplus per PSE&G residential

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[26] More precisely, our computation uses our estimate of temporary food and lodging costs to compute consumer surplus under a constant elasticity demand curve and then takes 50% of this value as the benefit of continued service, *i.e.* the midpoint between the estimated surplus at the limit price and zero. The choice of 50% is based on an assumption that the limit prices of customers varies between zero and our estimated price and is approximately evenly distributed (or, alternatively, is normally distributed) over this interval.

gas customer[27] per day (approximately $53), which we use as a proxy for the average daily value of avoiding an outage in gas service for the company's residential customers.

27 Some of PSE&G's customers are multiple households.

Table II-1
Consumer Surplus for PSE&G Residential Gas Customers

		Historical Price	Historical Quantity	Adjusted Consumer Surplus	Adjusted Consumer Surplus	Adjusted Consumer Surplus
		$/MMBtu	MMBtu	$millions	$ per household per day	$ per customer per day
		[1]	[2]	[3]	[4]	[5]
January	[a]	$10.52	30,025,072	$5,714	$88.10	$114.60
February	[b]	$10.58	21,727,191	$5,192	$88.62	$115.28
March	[c]	$9.84	18,842,681	$5,787	$89.22	$116.05
April	[d]	$10.66	9,612,372	$872	$13.88	$18.06
May	[e]	$11.50	4,810,179	$470	$7.25	$9.43
June	[f]	$12.17	3,753,671	$388	$6.19	$8.05
July	[g]	$12.52	3,402,936	$362	$5.59	$7.27
August	[h]	$13.13	2,867,311	$320	$4.94	$6.42
September	[i]	$12.76	3,022,102	$328	$5.22	$6.80
October	[j]	$11.47	5,396,171	$527	$8.12	$10.56
November	[k]	$10.63	10,791,729	$5,636	$89.79	$116.80
December	[l]	$8.79	16,970,453	$5,807	$89.53	$116.46
Annual	[m]	**$11.21**	**131,221,868**	**$31,403**	**$41.12**	**$53.49**

Sources and Notes:
[1]: Annual average based on EIA-176 data for PSE&G 2011 residential operations.
[2]: Annual average based on EIA-176 data for PSE&G 2011 residential operations.
[3]: *The Brattle Group* Analysis.
[4]: [3] / 2,092,314; household numbers from 2010 Census data.
[5]: [3] / 1,608,466; customer numbers from Table I-1.

C. Value Added Analysis

Many of PSE&G's commercial and industrial (C&I) customers are highly dependent upon access to natural gas, and prolonged service interruptions can have a significant impact on revenues and profits for C&I customers.[28] We use the average daily value added (VA) for C&I establishments in New Jersey as an indicator of those customers' profit margins, and thereby an upper end proxy for the value that they place upon avoiding an outage of gas service.[29]

Value added is roughly equivalent to profit margin; it is the sum of profit, depreciation, and labor costs. The sum of all value added by C&I establishments within the state sum to the state's Gross State Product (GSP). GSP, then, is considered to be the value of all of the economic output within the geographic confines of a state.[30] According to IHS Global Insights, the GSP for New Jersey for 2012 was approximately $506 billion. As described further below, we used GSP and value added data for New Jersey to determine the value that PSE&G's C&I gas customers place upon avoiding a gas outage.

We estimated an average level of value added across all of PSE&G's C&I customers in three steps. First, we started with 2012 GSP and value added by sector of the New Jersey economy (provided by 2-digit North American Industry Classification System, or NAICS, code).[31] We weighted these figures by the PSE&G gas customers as a percentage of total utility customers in New Jersey, thereby estimating the annual value added by PSE&G gas customers by NAICS code. Second, we obtained PSE&G gas consumption data broken down by the same 2-digit NAICS code, and also by whether the gas service was provided on a firm or interruptible basis.

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28 We recognize that some of PSE&G's C&I gas are supplied on an interruptible service basis, which implies that those customers can re-arrange production schedules and/or switch to other fuels if needed. Nonetheless, a forced gas outage can cause unplanned disruption and economic impacts. PSE&G's interruptible tariff is available to customers that have at least seven days' of alternative fuel available on-site, or which certify that they will shut down when interrupted (PSE&G tariff, rate schedule TSG-NF, sheet 101).

29 As indicated earlier, this value does not include private intangible benefits realized by the customer and its owners or employees, nor does it include the public or societal benefits of continued service.

30 GSP is also referred to as Gross Domestic Product (GDP) by State.

31 NAICS codes adopted by the U.S. Office of Management and Budget (OMB) in 1997 to replace the Standard Industrial Classification (SIC) system.

To be conservative, we excluded the value added for PSE&G's interruptible service, which minimized the economic impact that loss of gas service would have on these customers. This provided us with an "adjusted" GSP for those PSE&G customers in New Jersey. As shown in **Table II-2**, we estimated that the adjusted GSP for New Jersey to be approximately $102 billion.

Table II-2
Value Added for New Jersey Commercial and Industrial Customers

NAICS Category	New Jersey Annual GSP	PSE&G Gas Customer Annual Value Add	PSE&G Gas Customer Annual Consumption	PSE&G Gas Customer Firm Annual Consumption	PSE&G Firm Gas Customer Annual Value Add
	$millions	$millions	MMBtu	MMBtu	$millions
	[1]	[2]	[3]	[4]	[5]
Agriculture, Forestry, Fishing and Hunting	$612	$163	1,088,025	961,174	$144
Mining, Quarrying, and Oil and Gas Extraction	$49	$13	1,908,715	1,908,715	$13
Utilities	$9,004	$2,404	4,509,905	1,993,812	$1,063
Construction	$15,024	$4,011	46,452,855	44,622,281	$3,853
Manufacturing	$37,267	$9,950	127,408,806	82,505,349	$6,443
Wholesale Trade	$38,605	$10,307	57,373,184	45,757,965	$8,221
Retail Trade	$33,174	$8,857	66,391,932	51,549,533	$6,877
Transportation and Warehousing	$16,449	$4,392	10,233,692	10,233,692	$4,392
Information	$26,966	$7,200	10,428,185	7,505,379	$5,182
Finance and Insurance	$40,512	$10,816	320,010,457	23,145,384	$782
Real Estate and Rental and Leasing	$89,497	$23,895	108,558,249	100,914,812	$22,213
Professional, Scientific, and Technical Services	$47,654	$12,723	36,605,036	31,892,419	$11,085
Management of Companies and Enterprises	$13,468	$3,596	648,533	648,533	$3,596
Administrative and Support and Waste Management and Remediation Services	$17,332	$4,628	17,398,580	17,383,895	$4,624
Educational Services	$4,463	$1,192	90,774,039	67,842,301	$891
Health Care and Social Assistance	$37,912	$10,122	273,489,263	81,729,562	$3,025
Arts, Entertainment, and Recreation	$4,322	$1,154	10,141,821	10,141,821	$1,154
Accommodation and Food Services	$11,992	$3,202	63,164,717	60,291,010	$3,056
Other Services (except Public Administration)	$9,555	$2,551	58,522,394	57,156,591	$2,492
Public Administration	$52,053	$13,898	34,004,496	31,499,670	$12,874
Total	**$505,909**	**$135,075**	**1,339,112,886**	**729,683,898**	**$101,980**

Sources and Notes:
[1]: IHS Global Insights, Gross State Product for New Jersey in 2012.
[2]: [1] * 27%, where 27% is the PSE&G's gas customer share of total New Jersey Commercial and Industrial customers. 27% calculated as PSE&G C&I customers (157,389 according to PSE&G) divided by the total number of New Jersey C&I customers (589,495 according to EIA-861).
[3]: PSE&G 2011 C&I consumption data.
[4]: PSE&G 2011 C&I firm consumption data.
[5]: [2] * [4] / [3]

The sum of the adjusted GSP for PSE&G gas customers can then be divided by the total number of PSE&G C&I gas customers[32] to estimate the average value added per C&I customer. Specifically, the $102 billion in adjusted value added was divided by 157,389 customers, which yields a value added per average (firm) PSE&G C&I customer of approximately $1,775 per day.

D. COMPARISON AND RECONCILIATION

The values of avoiding electric and gas outages as estimated using the three methodologies described above are summarized in **Table II-3**. VOLLs per unserved kWhs were converted into average daily values for residential, commercial and industrial customers to allow for a comparison to the daily based values of mitigating outages to gas customers.

Table II-3
Value of Electricity and Natural Gas Service

		Electric		Gas	
Customer Class		Per Unserved kWh	Per Customer Per Day	Per Customer Per Day	Per Customer Per Day, adjusted
		[1]	[2]	[3]	[4]
Residential	[a]	$0.92	$18	$53	$53
Commercial	[b]	$49.17	$11,594		
Industrial	[c]	$11.29	$14,164		
Combined C&I	[d]	$47.94	$11,678	$2,351	$1,775
Alternate Combined C&I	[e]	$11.29	$3,037		

Sources and Notes:
[1a] through [1c]: See Figure II-2 and accompanying discussion.
[2a]: [1a] x 0.83 kW per hour x 24 hours.
[2b]: [1b] x 9.82 kW per hour x 24 hours.
[2c]: [1c] x 52.27 kW per hour x 24 hours.
[1d]: Average of [1b] and [1c], weighted by number of customers shown in Table I-1.
[2d]: Average of [2b] and [2c], weighted by number of customers shown in Table I-1.
[1e]: Example of setting Commercial VOLL equal to Industrial VOLL.
[2e]: [1e] x 11.21 kW per hour x 24 hours.
[3]: See Table II-1 (Consumer Surplus) and Value Added analysis above.
[4]: Adjusted to exclude non-firm C&I customers.

[32] Strictly, this should be the number of firm customers, but we understand that the number of PSE&G non-firm customers is very small relative to the total customer base.

Three key findings can be inferred from the table. First, the daily value of avoiding the loss of electric load for residential customers (approximately \$18) is considerably less than the average annual daily value that those customers place on losing gas service (*i.e.,* nearly \$53 per day). This is most likely explained by the premium placed on heating (particularly over longer outages). Our estimate of the value that residential gas customers place on avoiding losing gas service in non-heating months is much lower; *i.e.*, less than \$10 per day. Thus, our calculations suggest that non-heating-season gas service valued at about half the value of electric service by average residential customers.

Our second big finding is that the value added estimated for C&I gas customers is less than the VOLL for commercial and/or industrial electric customers or for the average VOLL for C&I electric customers. This difference is significantly reduced when the commercial VOLL per unserved kWh is set equal to the VOLL for industrial customers (*i.e.*, \$11.29 per unserved kWh).[33]

Our third key finding is that commercial and industrial business applications and processes are generally more dependent upon reliable electric service than upon reliable gas service (except for those instances in which industrial processes rely heavily on natural gas as a fuel). Thus, having electric VOLLs higher than the value levels used for gas service is internally consistent.

Therefore, we use the VOLLs provided in **Table II-3**, which reflect our conservative approach concerning the VOLLs for small and medium C&I electric customers, when estimating the benefits associated with PSE&G's Electric ES investments. We use consumer surplus (as adjusted, for residential customers) and value added (as adjusted, for C&I customers) in estimating the benefits associated with PSE&G's Gas ES investments.

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[33] The remaining gap between the average daily value placed by C&I customers on avoiding a loss of electric service and the estimate of average daily value-added by C&I customers may be explained by the impact of fixed costs in the C&I production function. As indicated earlier, value added is measured as the sum of profits, depreciation, and labor costs. However, C&I customers also have certain fixed costs which are incurred even when they are unable to operate because of a loss of power or natural gas – which, in turn, may lead to average C&I VOLLs being higher than average value added for C&I customers.

III. ENERGY STRONG - ELECTRIC

A. PSE&G ELECTRIC SYSTEM PERFORMANCE

Electric delivery utilities are focused on transporting electric power in a safe and reliable manner to customers over their transmission and distribution facilities. Their performance is typically measured in terms of the extent to which they deliver continuously reliable electricity to their customers. Service interruptions, or outages, are measured in terms of duration and frequency – using specific measures known as SAIDI, SAIFI and CAIDI – which can be reported for the company as a whole or by geographic or other sub-divisions.

- SAIDI is a measure of the average duration of outage, defined as the sum of all customer interruption durations (in minutes) divided by the total customers served.
- SAIFI is a measure of the average frequency of outages, defined as the total number of customer interruptions divided by the total number of customers served.
- CAIDI is a measure of the average outage for each customer actually affected by outages. It is considered an indicator for the time required to restore customers to service, and measured as SAIDI divided by SAIFI.

Interruptions in customer service can result from a variety of causes, including many of which are beyond the control of the electric delivery utility. For example, inadequate generating capacity and/or congestion in the high voltage segment of the electric system do not reflect failures within the electric delivery system, but are nonetheless included in SAIDI and SAIFI statistics. Historically, however, most outages have been attributed to distribution system related causes and, thus, SAIDI, SAIFI and CAIDI are generally viewed as indicators of electric delivery performance.

Major weather events are also out of the control of an electric utility. Thus, reliability indicators are frequently tracked both including and excluding such events. "SAIDI-x" refers to the duration statistic excluding interruptions that are caused by major weather events. SAIDI-x (as well as SAIFI-x and CAIDI-x) provide indicators of utility performance under normal (or close to normal) conditions, over which utility investment, operations and maintenance decisions and practices should have considerable influence.

Utilities and state regulators do not have completely consistent definitions of the interruptions that should be included and excluded from "normal" SAIDI, SAIFI and CAIDI but generally attempt to distinguish controllable outages from uncontrollable outages. In New Jersey, major events (*i.e.*, those excluded from routinely reported SAIDI, SAIFI and CAIDI statistics) are interruptions which affect "at least 10% of the customers in an operating area."[34]

The electric distribution system is made up of thousands of components, including lines stretched out over the entirety of the service territory as well as transformers, switches, and substations, among other componentry. Under normal conditions, service interruptions caused by problems with individual circuits or even substations affect a relatively small percentage of customers. More wide scale events, such as major storms and failures in the power generation or transmission systems, tend to be infrequent but are also far reaching when they do occur. The practice in New Jersey of excluding events which affect 10% or more of customers effectively excludes major events; electric delivery utilities in the State, thus, routinely track and report reliability statistics which generally reflect the performance of their assets.

The number of customer minutes of interruption (CMI) in total experienced by PSE&G customers (excluding outages associated with major events) from 2002 through 2012 is shown in **Figure III-1**. As is indicated in the figure, in the past five years PSE&G's electric customers experienced 95 million to 124 million minutes of service interruptions per year.

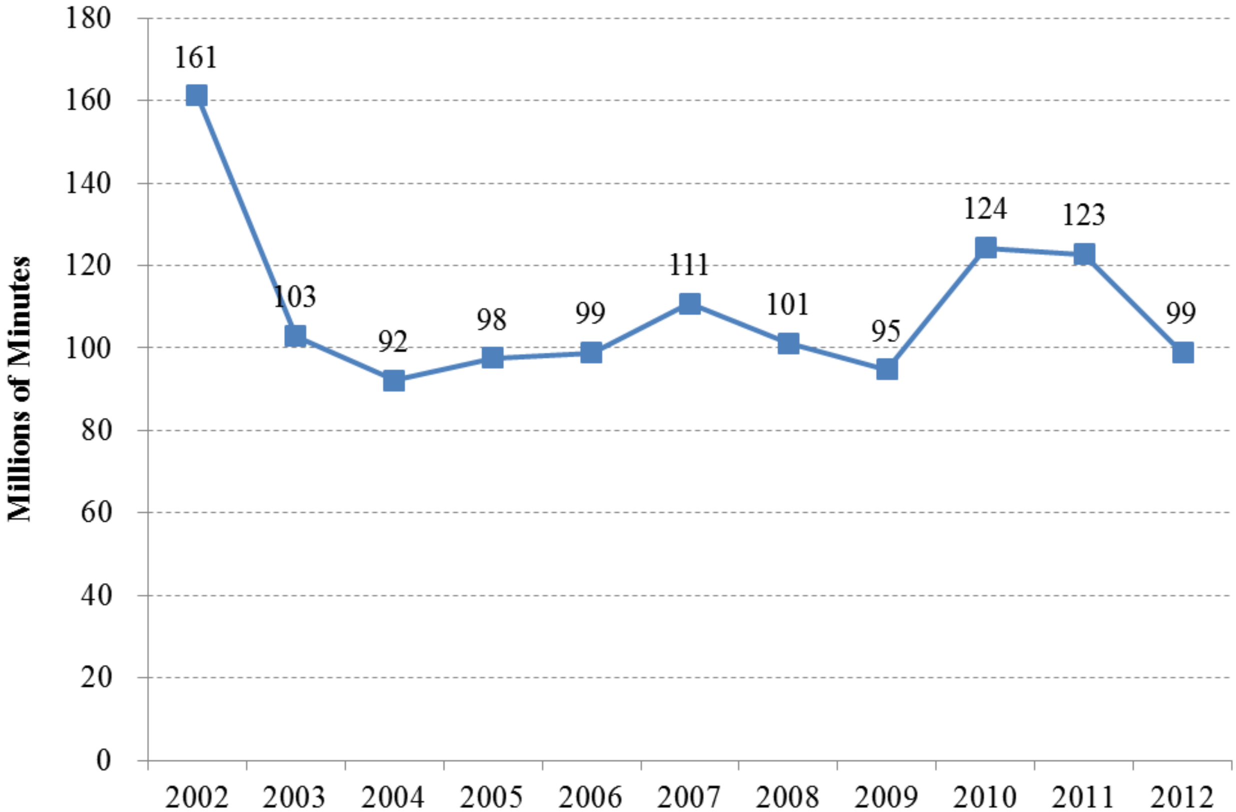
PSE&G's customer minutes of interruption data can be combined with data on customers in service to estimate the company's SAIDI, SAIFI and CAIDI statistics, as is shown in **Table III-1**. As indicated in the table, on average PSE&G customers experienced about 46 minutes of service interruptions in 2012. This level of electric delivery reliability appears superior to many other utilities, although comparisons across electric utilities are challenging because of differences in classifying major events (which are typically excluded from basic reliability statistics) and utility system characteristics.[35] Nonetheless, PSE&G's comparatively highly

34 New Jersey Administrative Code 14:5-1.2.

35 For example, the system wide SAIDI for Consolidated Edison has been lower (*i.e.*, higher reliability) than PSE&G's because Con Ed's has a networked and largely underground system while PSE&G serves a largely suburban area with an overhead and radial distribution system.

ranked level of reliability in its electric delivery system resulted in it winning the ReliabilityOne award for the mid-Atlantic states in 2012.[36]

Figure III-1
PSE&G Annual Customer Minutes of Interruption (CMI)
Excluding Outages Associated With Major Events
(Millions of Minutes)



Source: PSE&G Annual System Performance Reports.

Note: Reported CMIs (and shown in the graphic above) excludes minutes of service interruptions that are associated with major events, defined as outages that affect 10% of PSE&G customers located in a PSE&G operating area.

[36] The ReliabilityOne award is presented by PA Consulting based on relative utility performance in standard industry reliability statistics that measure the frequency and duration of electric power outages.

Table III-1
PSE&G Electric Delivery
Reliability Statistics

Year		CMI (minutes)	PSE&G Electric Customers	SAIDI (minutes)	SAIFI (outages)	CAIDI (minutes)
		[1]	[2]	[3]	[4]	[5]
2002	[a]	161,175,480	2,039,536	79.03	0.81	97.56
2003	[b]	102,915,360	2,053,366	50.12	0.63	79.56
2004	[c]	92,168,700	2,073,783	44.44	0.64	69.44
2005	[d]	97,563,600	2,086,306	46.76	0.69	67.77
2006	[e]	98,887,080	2,074,061	47.68	0.69	69.10
2007	[f]	110,800,800	2,090,895	52.99	0.76	69.73
2008	[g]	101,089,440	2,101,236	48.11	0.70	68.73
2009	[h]	94,722,360	2,122,389	44.63	0.70	63.76
2010	[i]	124,306,020	2,145,269	57.94	0.84	68.98
2011	[j]	122,794,920	2,146,947	57.20	0.78	73.33
2012	[k]	98,854,424	2,154,418	45.88	0.67	68.48

Sources and Notes:
[1]: See Figure III-1.
[2]: FERC Form 1, Electric Operating Revenues table.
[3]: [1] / [2]
[4a] through [4j]: PSE&G Annual System Performance Report 2011, page 14..
[4k]: PSE&G Electric Delivery Distribution Performance Report Review through December 31, 2012, page 7.
[5]: [3] / [4]

The level of CMI, and the resulting measures of system reliability, tends to increase dramatically when outages associated with major events are included.

Table III-2 presents the CMI excluding that for major events for 2011 and 2012, and also estimates the CMIs for major events in 2011 (including that for Hurricane Irene and the October snow storm) and the CMIs estimated to be associated with Superstorm Sandy.

The table shows that the CMI increased from roughly 123 million minutes (excluding the impact of major events) in 2011 to nearly 2 billion minutes after major events were included for that year. The increase is still more pronounced for 2012 when the impact from Superstorm Sandy is included. For 2012, the CMI was 99 million minutes (excluding major events) and over 9.8 billion minutes after including outages associated with Superstorm Sandy. The impact on SAIDI is equally notable: SAIDI-x in 2011 was roughly 57 minutes, while that year's SAIDI-with was over 900 minutes; SAIDI-x in 2012 was approximately 46 minutes, and SAIDI-with was over 4500 minutes. In short, Superstorm Sandy caused roughly 100 times normal levels of customer interruptions on PSE&G's electric system.

Table III-2
PSE&G Customer Minutes of Interruption and Outage Statistics
Excluding and Including Major Events
(2011 and 2012)

Major Events and Dates			2011 CMI (million minutes)	2011 SAIDI (minutes)	2012 CMI (million minutes)	2012 SAIDI (minutes)
			[1]	[2]	[3]	[4]
CMI-x		[a]	123	57.20	99	45.88
Event 1	2/2/2011	[b]	10.2	4.74	-	-
Event 2	7/22/2011	[c]	9.9	4.60	-	-
Event 3	7/29/2011	[d]	14.0	6.51	-	-
Event 4 - Hurricane Irene	8/27/2011 to 9/1/2011	[e]	1,002.4	466.91	-	-
Event 5 - October Snow Storm	10/29/2011 to 11/4/2011	[f]	835.7	389.27	-	-
Event 6 - Superstorm Sandy	10/27/2012 to 11/14/2012	[g]	-	-	9,750	4,525.46
Total Major Events		[h]	1,872	872.03	9,750	4,525.46
Total - CMI-with		[i]	1,995	929.22	9,849	4,571.35

Sources and Notes:
[a]: Table III-1.
[b] through [g]: PSE&G IEEE Storm Outage Data.
[h]: total of [b] through [g]
[1i] and [3i]: [a] + [h]
[2h]: [1h] x 1,000,000 / 2,146,947.
[4h]: [3h] x 1,000,000 / 2,154,418.
[2i]: [1i] x 1,000,000 / 2,146,947.
[4i]: [3i] x 1,000,000 / 2,154,418.

B. ENERGY STRONG ELECTRIC INVESTMENTS

PSE&G's proposed Energy Strong investments in its electric delivery system are targeted at hardening infrastructure (so that it will be more likely to withstand the impacts of severe weather) and making its system more resilient (so it will be able to be brought back on-line quicker if it is damaged by storms). PSE&G expects that these investments will likely improve the system's day-to-day reliability, including reliability with respect to the many weather-related challenges to the system throughout the year that do not ultimately give rise to qualified "major events." Those improvements may be significant and are welcome by-products of the targeted goals of higher levels of reliability and resiliency during major weather events.

The Energy Strong proposal covers three primary program areas:

- **Infrastructure (Asset) Hardening** covers ten sub-programs, including station flood and storm surge mitigation, enhancement of outside plant construction standards, strengthening pole infrastructure, undergrounding parts of the overhead system that are particularly susceptible to storm damage, and relocating operations and emergency response centers.

- **System Resiliency** covers eight sub-programs and is primarily concerned with applying advanced technologies (such as remote controls, sensors and broadband communications) to improve system visibility and improve outage detection and responsiveness. It also involves applying smart switches and fuses and adding them within PSE&G's loop scheme.

- **The Supplemental Investment Area** covers two sub-programs, one involving backup generators and the other a pilot program to engage municipal resources in vegetation management and in storm responses.

A summary of the programs (and sub-programs) and the level of associated investment are included in **Table III-3.**

Table III-3
PSE&G Electric Energy Strong Proposal
Investment Cost By Sub-Program

Program	Sub-Program	Invest Areas	Description		Proposed Investment (2012$ millions): Investment: Months 1 - 60		Investment: Months 61 - 120		Total Investment	
					$	%	$	%	$	%
Asset Hardening	1	1	Station Flood Mitigation		$819	29.7%	$859	31.1%	$1,678	60.8%
Asset Hardening	2	3	Enhance OP Construction Standards		$135	4.9%	$0	0.0%	$135	4.9%
Asset Hardening	3	1	Strengthening Pole Infrastructure		$105	3.8%	$0	0.0%	$105	3.8%
Asset Hardening	4	1	Rebuild/Relocate Backyard Poles		$100	3.6%	$0	0.0%	$100	3.6%
Asset Hardening	5	3	Undergrounding		$76	2.8%	$0	0.0%	$76	2.8%
Asset Hardening	6	1	Relocate Critical PSE&G Operating Centers		$15	0.5%	$0	0.0%	$15	0.5%
Total Asset Hardening		10			$1,250	45.3%	$859	31.1%	$2,109	76.4%
System Resiliency	1	1	Advanced Technologies - System Visibility	Micro Relays and SCADA eqpt	$120	4.3%	$130	4.7%	$250	9.1%
System Resiliency	1	1	Advanced Technologies - System Visibility	Distribution Management System	$24	0.9%	$26	0.9%	$50	1.8%
System Resiliency	1	1	Advanced Technologies - Comm Network	Fiber Optic Network	$35	1.3%	$38	1.4%	$73	2.6%
System Resiliency	1	1	Advanced Technologies - Comm Network	Satellite Comm	$3	0.1%	$0	0.0%	$3	0.1%
System Resiliency	1	1	Advanced Technologies - Storm Damage Assess	Advanced Distribution Management System	$9	0.3%	$6	0.2%	$15	0.5%
System Resiliency	1	1	Advanced Technologies - Storm Damage Assess	Enhanced Storm Management Systems	$50	1.8%	$0	0.0%	$50	1.8%
System Resiliency	1	1	Advanced Technologies - Storm Damage Assess	Expand Communications Channels	$10	0.4%	$0	0.0%	$10	0.4%
System Resiliency	2	1	Contingency Reconfiguration Strategies		$200	7.2%	$0	0.0%	$200	7.2%
Total System Resiliency		8			$451	16.3%	$200	7.2%	$651	23.6%
Supplemental	1	1	Emergency Backup Generator and Quick Connects		$2	0.1%	$0	0.0%	$2	0.1%
Supplemental	2	1	Muni Pilot Program		$0	0.0%	$0	0.0%	$0	0.0%
Total Supplemental		2			$2	0.1%	$0	0.0%	$2	0.1%
Total Energy Strong - Electric		20			$1,703	61.7%	$1,059	38.3%	$2,762	100.0%

Source: PSE&G Energy Strong Filings, BPU Docket Nos. EO13020155 and GO13020156.

Of the total $2.76 billion proposed Energy Strong investment in PSE&G's electric system, nearly 62% is planned to be expended within five years of approval by the BPU; the remainder is expected to be invested in the latter 60 months of the program. PSE&G's proposed program to mitigate the impacts of flood and storm surges on sub-stations, with a projected cost of approximately $1.7 billion over the next 10 years (roughly 61% of total Energy Strong investments) represents the single largest investment sub-program. Programs that apply advanced technologies to improve system resiliency through increased system visibility and outage detection and responsiveness account for about 16% of total proposed Energy Strong investment. This area - System Resiliency Sub-Program 1, Advanced Technologies - includes seven specified areas of investment, which together enable more advanced distribution management and storm management systems than are currently in place at PSE&G. The Contingency Reconfiguration sub-program accounts for roughly 7% of the total Energy Strong investment.

C. Customers Affected

PSE&G estimated the number customers that will be affected by each of the Electric ES sub-programs.

Table III-4 segments the Electric ES sub-programs into investments targeted at: 1) individual circuits; 2) groups of customers served by substations and/or distribution feeders; 3) all PSE&G customers (which is further segmented between sub-programs involving System Resiliency and the relocation of key PSE&G operating centers).

Table III-4
Summary of Customers Affected By Energy Strong Electric Sub-Program Investments

Program	Sub-Program	Description	Investment Initiative / Action		Number of Customers Affected	Percent of PSE&G Total Customers	Investment ($ millions)	Percent of Energy Strong Investment
					[1]	[2]	[3]	[4]
Initiative Target: Individual Circuits / Customers								
Asset Hardening	2	Enhance OP Construction Standards	Convert 4kV distribution plant to 13kV standards	[a]	34,495	1.6%	$65	2.4%
Asset Hardening	2	Enhance OP Construction Standards	Convert 26kV distribution plant to 69kV standards (while still operating at 26kV)	[b]	29,873	1.4%	$60	2.2%
Asset Hardening	2	Enhance OP Construction Standards	Add spacer cable to eliminate open wire to targeted areas	[c]	7,357	0.3%	$10	0.4%
Asset Hardening	3	Strengthening Pole Infrastructure	Increased pole diameters, reduced span lengths and enhanced storm guying	[d]	48,474	2.3%	$102	3.7%
Asset Hardening	3	Strengthening Pole Infrastructure	Install non-wood poles	[e]	1,347	0.1%	$3	0.1%
Asset Hardening	4	Rebuild/Relocate Backyard Poles	Rebuild backyard poles (including tree trimming)	[f]	36,973	1.7%	$100	3.6%
Asset Hardening	5	Undergrounding	Convert targeted OH areas to UG	[g]	14,714	0.7%	$60	2.2%
Asset Hardening	5	Undergrounding	Replace PM transformers with submersibles (in target areas)	[h]	1,895	0.1%	$8	0.3%
Asset Hardening	5	Undergrounding	Replace ATS switches/transformers with submersible switches	[i]	-	0.0%	$8	0.3%
System Resiliency	2	Advanced Technologies	Contingency Reconfiguration Strategies - Create multiple system sections using smart switches, smart fuses, and adding redundancy within PSE&G loop scheme	[j]	245,824	11.4%	$200	7.2%
Supplemental	1	Emergency Backup Generator and Quick Connects	Deploy emergency generators (municipal determined priorities) and quick connects	[k]	200	0.0%	$2	0.1%
Supplemental	2	Storm Plan - Municipal Pilot Program	Veg managament, mobile field apps and CHP for critical municipal facilities	[l]	-	0.0%	$0	0.0%
Total Customers Affected: Individual Circuits / Customers					421,153	19.5%	$618	22.4%
Initiative Target: Substations / Feeder Groups								
Asset Hardening	1	Station Flood Mitigation	Raising/rebuilding infrastructure and installing flood walls.	[m]	748,500	34.7%	$1,678	60.8%
System Resiliency	1	Advanced Technologies	System Visibility- 26kV, 13kV, and 4kV Microprocessor Relays and SCADA field equipment (RTUs) to enable remote monitoring and operations	[n]	1,134,374	52.7%	$250	9.1%
Initiative Target: Operating Centers								
Asset Hardening	6	Relocate Critical PSE&G Operating	Relocate ESOC, GSOC, DERC and SR	[o]	2,154,418	100.0%	$15	0.5%
Initiative Target: System Wide								
System Resiliency	1	Advanced Technologies	System Visibility - SCADA monitors and servers, dispatch consoles, communications switches	[p]	2,154,418	100.0%	$50	1.8%
System Resiliency	1	Advanced Technologies	Communications Network - fiber optic transmission backbone and 91 of PSE&G's 125 distribution substations	[q]	2,154,418	100.0%	$73	2.6%
System Resiliency	1	Advanced Technologies	Communications Network - satellite communication program (pilot)	[r]	2,154,418	100.0%	$3	0.1%
System Resiliency	1	Advanced Technologies	Advanced Distribution Management System (ADMS) to integrate SCADA, DMS, OMS and GIS systems	[s]	2,154,418	100.0%	$15	0.5%
System Resiliency	1	Advanced Technologies	Enhance storm management systems	[t]	2,154,418	100.0%	$50	1.8%
System Resiliency	1	Advanced Technologies	Communication channels expansion to improve customer access to information (outage maps, mobile apps, preference management, SMS, mobile web)	[u]	2,154,418	100.0%	$10	0.4%
Total Customers Affected: System Wide					2,154,418	100.0%	$201	7.3%

Sources and Notes: PSE&G Energy Strong Filings, BPU Docket Nos. EO13020155 and GO13020156.
Column [1] Number of affected customers as estimated by PSE&G engineers..
[d] and [e]: Strengthening Pole Infrastructure sub-program was further divided into two parts to more accurately reflect number of customers affected.
[h] and [i] Customers affected under Replace ATS switches/transformers with submersible switches is included with Replace PM transformers.
[k]: Includes directly affected customers only; many additional customers may benefit from restoration of services at *e.g.*, gas stations or grocery stores.
[l]: Cost and number of customers affected for the Muni Pilot Program remain to be determined.
[o] through [u]: Total number of customers based on PSE&G's FERC Form 1 for 2012 (filed in March 2013).

As indicated in the table, most of the Electric ES investments are targeted at specific circuits (about 22%) and groups of customers served by specifically-targeted substations (roughly 61%). Investments in advanced technologies (*i.e.*, communications and information systems) that affect PSE&G's overall awareness of its distribution system (and hence benefit all of its customers overall) involve roughly 7.3% of total Electric ES investment.

With the exception of the Backyard Pole sub-program (Asset Hardening sub-program 4), PSE&G expects that all of its electric delivery sub-programs will affect residential, commercial and industrial customers in general proportion to the mix of customers on its electric system overall. **Table III-5** summarizes PSE&G's total electric system customers and kWh consumption in 2012.

Table III-5
PSE&G Energy Strong Proposal
PSE&G Customer Characteristics

Customer Class	Number of Customers	Electricity Consumption (kWh)
	[1]	[2]
Residential	1,871,700	13,543,739,000
Commercial	273,499	23,537,935,000
Industrial	9,219	4,221,150,000
Total Customers	2,154,418	41,302,824,000

Source: FERC Form 1, Electric Operating Revenues table.

D. VALUE OF AVOIDED OUTAGES

As indicated earlier, PSE&G's Electric ES investments are targeted at preventing and/or minimizing major outages, such as the outage following Hurricane Irene, the October Snowstorm and Superstorm Sandy. On average, the resulting outages were multi-day events, with some customers being without power for much longer periods. **Table III-6** provides an estimate of the kWhs that would go unserved if PSE&G experienced a hypothetical system-wide outage (*i.e.,* affecting all of its customers) for a period of 24 hours. The table indicates that PSE&G's 2,154,418 customers would be without power for approximately 51.7 million customer-hours, which would translate into roughly 113 million unserved kWhs.

Table III-6
PSE&G System-Wide Outage – 1 Day

Customer Class		Number of Customers	Outage Hours	Average kW per Customer per Hour	CMI	Unserved kWhs
		[1]	[2]	[3]	[4]	[5]
Residential	[a]	1,871,700	24	1	2,695,248,000	37,106,134
Commercial	[b]	273,499	24	10	393,838,560	64,487,493
Industrial	[c]	9,219	24	52	13,275,360	11,564,795
Total	[d]	2,154,418	24	2.2	3,102,361,920	113,158,422
kWh Per Outage Hour	[e]					4,714,934

Sources and Notes:
[1]: See Table III-5.
[2]: Assumed 24-hour outage.
[3]: Table III-5 [2] / Table III-5 [1] / 8760
[4]: [1] x [2] x 60
[5]: [1] x [2] x [3]

The Electric ES program covers a range of areas of investment which address multiple points of possible system failure. Some sub-programs are aimed at improving the reliability and/or resiliency for individual circuits or groups of circuits, while other investment areas are more system-wide in their scope. Thus, the various electric delivery sub-programs may benefit the same customers multiple times. For example, customers who are served by 4 kV distribution lines may benefit from the Asset Hardening sub-programs that 1) enhance overhead construction standards; 2) replace backyard poles; and 3) reduce flooding and storm surges at PSE&G substations. Those customers would likely also benefit from both System Resiliency sub-programs Advanced Technologies and Contingency Reconfiguration Strategies. We discuss our treatment of this phenomenon of overlap or coincidence of failure below. Initially, it is easier to present our results for each program on a standalone or *non-coincident* basis.

Table III-7 summarizes PSE&G's estimates of the percentages of affected customers that will avoid outages and/or will realize lessened outage durations as a result of PSE&G's circuit and substation based sub-programs. **Table III-8** summarizes PSE&G's estimates of percentages of customers that will avoid outages and/or will realize lessened outage durations as a result of PSE&G's system-wide sub-programs.

Table III-7
PSE&G Estimate of Impact On Outages
Circuit and Substation/Feeder Sub-programs

Program	Sub-Program	Investment Initiative / Action	% Customers Avoiding Major Outages	% Customers Experiencing Shortened Outages	% Reduced Outage Duration
			[1]	[2]	[3]
Initiative Target: Individual Circuits / Customers					
Asset Hardening	Enhance OP Construction Standards	Convert 4kV distribution plant to 13kV standards	20%	80%	10%
Asset Hardening	Enhance OP Construction Standards	Convert 26kV distribution plant to 69kV standards (while still operating at 26kV)	50%	50%	10%
Asset Hardening	Enhance OP Construction Standards	Add spacer cable to eliminate open wire to targeted areas	40%	0%	10%
Asset Hardening	Strengthening Pole Infrastructure	Increased pole diameters, reduced span lengths and enhanced storm guying	2%	0%	10%
Asset Hardening	Strengthening Pole Infrastructure	Install non-wood poles	2%	0%	10%
Asset Hardening	Rebuild/Relocate Backyard Poles	Rebuild backyard poles (including tree trimming)	50%	50%	10%
Asset Hardening	Undergrounding	Convert targeted OH areas to UG	60%	0%	10%
Asset Hardening	Undergrounding	Replace PM transformers with submersibles (in target areas)	90%	0%	10%
Asset Hardening	Undergrounding	Replace ATS switches/transformers with submersible switches	-	-	-
System Resiliency	Advanced Technologies	Create multiple system sections using smart switches, smart fuses, and adding redundancy within PSE&G loop scheme	10%	90%	10%
Supplemental	Emergency Backup Generator and Quick Connects	Deploy emergency generators (municipal determined priorities) and quick connects**	0%	100%	67%
Supplemental	Storm Plan - Municipal Pilot Program	Veg managament, mobile field apps and CHP for critical municipal facilities	-	-	-
Initiative Target: Substations Feeder Groups					
Asset Hardening	Station Flood Mitigation	Raising/rebuilding infrastructure and installing flood walls.	33%	66%	20%
System Resiliency	Advanced Technologies	System Visibility- 26kV, 13kV, and 4kV Microprocessor Relays and SCADA field equipment (RTUs) to enable remote monitoring and operations	0%	100%	6%

Sources and Notes: Estimates of percent impact from Electric ES sub-programs on outages developed by PSE&G.

Table III-8
PSE&G Estimate of Impact On Outages
System Wide Sub-programs

Program	Sub-Program	Investment Initiative / Action	% Customers Avoiding Major Outages	% Customers Experiencing Shortened Outages	% Reduced Outage Duration
			[1]	[2]	[3]
Initiative Target: Operating Centers					
Asset Hardening	Relocate Critical PSE&G Operating Centers	Relocate ESOC, GSOC, DERC and SR	0%	1%	8%
Initiative Target: System Wide					
		System Visibility - SCADA monitors and servers, dispatch consoles, communications switches			
		Communications Network - fiber optic transmission backbone and 91 of PSE&G's 125 distribution substations			
		Communications Network - satellite communication program (pilot)			
		Advanced Distribution Management System (ADMS) to integrate SCADA, DMS, OMS and GIS systems			
		Enhance storm management systems			
		Communication channels expansion to improve customer access to information (outage maps, mobile apps, preference management, SMS, mobile web)			
Avoided / Reduced CMI: System Wide			0%	100%	6%

Sources and Notes: Estimates of percent impact from Electric ES sub-programs on outages developed by PSE&G.
* Numbers shown for System Reliability Advanced Technology reflect 6 sub-program areas: SCADA monitors, fiber optic communications, satellite communications, Advanced Distribution Management (ADM), storm management systems, and communication channel enhancement (customer access). It does not include Advanced Technologies loop redundancy and remote monitoring, which are included in Table III-7.

Table III-9 and **Table III-10**, then, estimate the CMIs and the unserved kWhs avoided and/or reduced as a result of these investments for a hypothetical 24 hour outage.[37] These sub-programs may, by themselves, prevent a customer from losing power or may reduce outage duration. However, the multiple points of failure addressed means that the sub-programs frequently benefit the same customers. Accordingly, the number included in these tables are non-coincident, *i.e.,* not adjusted for overlap.

[37] Using a 24 hour outage is a stylized analysis that facilitates putting the potential impact of the Energy Strong program in context. The avoided CMIs and estimates of VOLLs presented later in this report are based on outages of longer durations. It is possible that the degree of outage reductions and/or reductions that were estimated by PSE&G for multi-day outages will not be completely transferrable to outages of shorter durations, but there is no obvious upward or downward bias in our calculation.

Table III-9
Estimate of Avoided / Reduced Non-coincident CMI and Non-coincident Unserved kWhs
For 1 Day Outage
Circuit and Substation/Feeder Sub-programs

Program	Sub-Program	Investment Initiative / Action		Total CMI Avoided / Reduced	Total unserved kWh Avoided / Reduced	Residential Unserved kWh Avoided / Reduced	Commercial Unserved kWh Avoided / Reduced	Industrial Unserved kWh Avoided / Reduced
				[1]	[2]	[3]	[4]	[5]
Initiative Target: Individual Circuits / Customers								
Asset Hardening	Enhance OP Construction Standards	Convert 4kV distribution plant to 13kV standards	[a]	13,908,525	507,312	166,354	289,111	51,847
Asset Hardening	Enhance OP Construction Standards	Convert 26kV distribution plant to 69kV standards (while still operating at 26kV)	[b]	23,659,614	862,983	282,983	491,802	88,197
Asset Hardening	Enhance OP Construction Standards	Add spacer cable to eliminate open wire to targeted areas	[c]	4,237,719	154,570	50,686	88,088	15,797
Asset Hardening	Strengthening Pole Infrastructure	Increased pole diameters, reduced span lengths and enhanced storm guying	[d]	1,396,063	50,921	16,698	29,019	5,204
Asset Hardening	Strengthening Pole Infrastructure	Install non-wood poles	[e]	38,780	1,414	464	806	145
Asset Hardening	Rebuild/Relocate Backyard Poles	Rebuild backyard poles (including tree trimming)	[f]	29,282,616	403,141	403,141	-	-
Asset Hardening	Undergrounding	Convert targeted OH areas to UG	[g]	12,713,156	463,711	152,057	264,263	47,391
Asset Hardening	Undergrounding	Replace PM transformers with submersibles (in target areas)	[h]	2,456,332	89,595	29,379	51,059	9,157
Asset Hardening	Undergrounding	Replace ATS switches/transformers with submersible switches	[i]	-	-	-	-	-
System Resiliency	Advanced Technologies	Create multiple system sections using smart switches, smart fuses, and adding redundancy within PSE&G loop scheme	[j]	67,257,446	2,453,210	804,440	1,398,052	250,718
Supplemental	Emergency Backup Generator and Quick Connects	Deploy emergency generators (municipal determined priorities) and quick connects	[k]	192,000	7,003	2,296	3,991	716
Supplemental	Storm Plan - Municipal Pilot Program	Veg managament, mobile field apps and CHP for critical municipal facilities	[l]	-	-	-	-	-
Avoided / Reduced CMI: Individual Circuits / Customers			[m]	155,142,251	4,993,862	1,908,499	2,616,191	469,172
Initiative Target: Substations Feeder Groups								
Asset Hardening	Station Flood Mitigation	Raising/rebuilding infrastructure and installing flood walls.	[n]	497,962,080	18,163,130	5,955,929	10,350,928	1,856,273
System Resiliency	Advanced Technologies	System Visibility- 26kV, 13kV, and 4kV Microprocessor Relays and SCADA field equipment (RTUs) to enable remote monitoring and operations	[o]	90,749,920	3,310,097	1,085,424	1,886,380	338,292
Avoided / Reduced CMI: Substations / Feeder Groups			[p]	588,712,000	21,473,227	7,041,353	12,237,309	2,194,564
Avoided / Reduced CMI: Circuit- and Substation-based sub-programs			[q]	743,854,251	26,467,088	8,949,852	14,853,500	2,663,736

Sources and Notes:

[1]: Table III-4 [1] x 1440 x (Table III-7 [1] + Table III-7 [2] x Table III-7 [3]); 1440 = minutes in 1 day

[2]: [3] + [4] + [5]

[3]: [1] x 86.88% Residential Customer Share x Table III-6 [3a] / 60

[3f]: [1] x Table III-6 [3a] / 60

[4]: [1] x 12.69% Commercial Customer Share x Table III-6 [3b] / 60

[5]: [1] x 0.43% Industrial Customer Share x Table III-6 [3c] / 60

Table III-9 indicates that approximately 12.4 million non-coincident hours of outage would be avoided and/or reduced as a result of the circuit and substation based sub-programs, which translates into 26.5 million non-coincident unserved kWhs. Roughly 2/3rds of the avoided or reduced non-coincident CMIs are attributable to the Substation Flood and Storm Surge Mitigation sub-program, and approximately 21% of calculated avoided and/or reduced non-coincident CMIs are attributable to sub-programs aimed at individual circuits or customers.

Table III-10 indicates that approximately 2.9 million non-coincident customer-hours of outage would be reduced as a result of the Advanced Technologies and the Operation Centers Relocations sub-programs, which translates into 6.4 million non-coincident unserved kWhs. Both of these sub-programs have the potential to affect all PSE&G customers. Neither will prevent outages from occurring but both may be instrumental in bringing customers back on line following an outage (and therefore could reduce outage duration). PSE&G estimates that the Advanced Technologies sub-program may reduce outage times by roughly 6%.[38]

A major weather event involving flooding could also affect PSE&G's operation centers. Such a prospect of flooding, as was nearly the case during Superstorm Sandy, would have a significant effect on all customers, and may set back restoration efforts by 5 to 6 hours in a multi-day outage event.[39] PSE&G engineers estimate that this is a real but low probability event. Accordingly, to reflect this low probability, they applied the reduced outage duration to only 1% of its customers.

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[38] PSE&G's estimate was based on an estimate four hour reduction in outage duration over the course of a 72 hour outage.

[39] Five to six hours represents the time required to relocate controls to an alternate location. This time divided by a 72 hour outage results in roughly an 8% change in restoration time.

Table III-10
Estimate of Avoided / Reduced Non-coincident CMI and Non-coincident Unserved kWhs
For 1 Day Outage
System Wide Sub-programs

Program	Sub-Program	Investment Initiative / Action	Total CMI Avoided / Reduced (Minutes)	Total unserved kWh Avoided / Reduced (kWh)	Residential Unserved kWh Avoided / Reduced	Commercial Unserved kWh Avoided / Reduced	Industrial Unserved kWh Avoided / Reduced
			[1]	[2]	[3]	[4]	[5]
Initiative Target: Operating Centers							
Asset Hardening	Relocate Critical PSE&G Operating Centers	Relocate ESOC, GSOC, DERC and SR	2,585,302	94,299	30,922	53,740	9,637
Initiative Target: System Wide							
		System Visibility - SCADA monitors and servers, dispatch consoles, communications switches					
		Communications Network - fiber optic transmission backbone and 91 of PSE&G's 125 distribution substations					
		Communications Network - satellite communication program (pilot)					
		Advanced Distribution Management System (ADMS) to integrate SCADA, DMS, OMS and GIS systems					
		Enhance storm management systems					
		Communication channels expansion to improve customer access to information (outage maps, mobile apps, preference management, SMS, mobile web)					
Avoided / Reduced CMI: System Wide			172,353,440	6,286,579	2,061,452	3,582,639	642,489
Avoided / Reduced CMI: System-wide sub-programs			174,938,742	6,380,878	2,092,374	3,636,378	652,126

Sources and Notes:
[1]: Table III-4 [1] x 1440 x (Table III-8 [1] + Table III-8 [2] x Table III-8 [3])
[2]: [3] + [4] + [5]
[3]: [1] x 86.88% Residential Customer Share x Table III-6 [3a]
[4]: [1] x 12.69% Commercial Customer Share x Table III-6 [3b]
[5]: [1] x 0.43% Industrial Customer Share x Table III-6 [3c]
* System Resiliency Advanced Technologies line includes the 6 sub-program areas summarized in Table III-8. The other System Resiliency Advanced Technology sub-program elements are included in Table III-9.

The sum of the avoided and/or reduced non-coincident CMIs and unserved kWhs resulting from the three electric delivery investment programs equals approximately 15.3 million non-coincident hours of outage and 32.9 million non-coincident unserved kWhs over the course of a hypothetical 24 hour outage. However, as noted above, it is likely that a major event will affect a number of points of failure (and for events such as Superstorm Sandy, a very large portion) and restoration efforts will be completed at least partially in parallel. We adjust for this factor in the following subsection.

E. COSTS AND PARTIAL PRIVATE BENEFITS

The benefits associated with the Electric ES program investments can be estimated by applying the VOLL methodology discussed in Chapter II. VOLLs (for each customer class) on a dollar per unserved kWh basis can be applied to outage data to estimate 1) the cost to customers of experiencing an outage, and 2) the savings to customers from avoiding experiencing an outage.

When analyzing the total impact of the entire program it is necessary to estimate the total storm-induced outage duration we expect customers to experience in the absence of the Electric ES investment program as a whole. However, this total estimate of outage duration will differ from the sum of the outage durations that are projected to be avoided as a result of each individual Electric ES sub-program. This is because the Electric ES sub-programs reflect numerous potential points of electric system failure. Restoring power, in the event of an outage, would likely involve repair crews working in parallel (as opposed to serially). Thus, for example, a two-day outage caused by a pole collapse on a customer's street could occur (and be fixed) during the same two days as the substation serving that customer was also fixed. The total duration of the customer's outage would then have been two days, not the sum of the separate two-day outages. We adjust for this *coincidence* when assessing the overall (albeit partial) outage benefits of PSE&G's Electric ES sub-programs.

Table III-11 uses the outage data for a hypothetical 24 hour outage to estimate the cost to customers from such an event. The table indicates that the hypothetical system-wide 24 hour outage (*i.e.,* approximately 113 million unserved kWhs) would cost customers approximately

$3.3 billion, based on the VOLLs per unserved kWh for each customer class provided in Chapter II.

This same approach can be applied to the unserved kWhs avoided as a result of the effectiveness of the Electric ES investments. **Table III-12** applies the VOLL per unserved kWh estimates to the non-coincident unserved kWhs avoided for each customer class developed in **Table III-9** and **Table III-10.**

Table III-11
Estimate of Total VOLL Value
PSE&G System-Wide Hypothetical 1 Day Outage

Customer Class		Number of Customers	Unserved kWhs	VOLL ($ per Unserved kWh)	Total VOLL
		[1]	[2]	[3]	[4]
Residential	[a]	1,871,700	37,106,134	$0.92	$34,107,816
Commercial	[b]	273,499	64,487,493	$49.17	$3,170,909,519
Industrial	[c]	9,219	11,564,795	$11.29	$130,581,186
Total	[d]	2,154,418	113,158,422	$29.48	$3,335,598,521
kWh Per Outage Hour	[e]		4,714,934		
VOLL Per Outage Hour	[f]				$138,983,272

Sources and Notes:
[1]: See Table III-5.
[2]: See Table III-6.
[3]: See Table II-3.
[4]: [2] x [3]
[e]: [2d] / 24
[f]: [4d] / 24

Table III-12
Estimated Unserved Non-coincident kWh (Avoided) and VOLLs By Customer Class
As Result Of Energy Strong Electric Delivery Investments
Hypothetical 1 Day Outage

Customer Class Unserved kWh (Avoided) and VOLLs		Individual Circuits / Customers	Substations / Feeder Groups	System Wide - Operating Centers	System Wide - System Resiliency	Total ES Electric Delivery Programs
		[1]	[2]	[3]	[4]	[5]
Residential Unserved kWh Avoided	[a]	1,908,499	7,041,353	30,922	2,061,452	11,042,226
Residential VOLL per Unserved kWh	[b]	$0.92	$0.92	$0.92	$0.92	$0.92
Total Residential VOLL	[c]	$1,754,285	$6,472,385	$28,423	$1,894,879	$10,149,971
Commercial Unserved kWh Avoided	[d]	2,616,191	12,237,309	53,740	3,582,639	18,489,878
Commercial VOLL per Unserved kWh	[e]	$49.17	$49.17	$49.17	$49.17	$49.17
Total Commercial VOLL	[f]	$128,640,540	$601,719,765	$2,642,425	$176,161,640	$909,164,370
Industrial Unserved kWh Avoided	[g]	469,172	2,194,564	9,637	642,489	3,315,862
Industrial VOLL per Unserved kWh	[h]	$11.29	$11.29	$11.29	$11.29	$11.29
Total Industrial VOLL	[i]	$5,297,545	$24,779,414	$108,818	$7,254,510	$37,440,287
Total Customers Unserved kWh Avoided	[j]	4,993,862	21,473,227	94,299	6,286,579	32,847,966
Average VOLL per Unserved kWh	[k]	$27.17	$29.48	$29.48	$29.48	$29.13
Total Customer VOLL	[l]	$135,692,370	$632,971,564	$2,779,665	$185,311,029	$956,754,628

Sources and Notes:
[a], [d], and [g]: See Table III-9 and Table III-10
[b], [e], and [h]: See Table III-11
[c]: [a] x [b]
[f]: [d] x [e]
[i]: [g] x [h]
[j]: [a] + [d] + [g]
[k]: [l] / [j]
[l]: [c] + [f] + [i]
[5]: [1] + [2] + [3] + [4]

The table indicates that Electric ES sub-program investments could reduce the impact of the hypothetical 24 hour outage by nearly 33 million unserved kWhs, saving customers roughly $957 million in VOLL. **Table III-13** summarizes our Base Case, which assumes that a major weather event results in three-day outage on average for all affected customers, which reflects PSE&G's experience with Superstorm Sandy and fully incorporates the realized coincidence in PSE&G's actual response to the storm. The table indicates that under these circumstances, PSE&G's Electric ES sub-program investments could reduce the impact of this outage by nearly 99 million unserved kWhs, saving customers roughly $2.9 billion in VOLL.

Table III-13
Estimated Unserved Non-coincident kWh (Avoided) and VOLLs By Customer Class
As Result Of Energy Strong Electric Delivery Investments
3 Day Outage

Customer Class Unserved kWh (Avoided) and VOLLs		Individual Circuits / Customers	Substations / Feeder Groups	System Wide - Operating Centers	System Wide - System Resiliency	Total ES Electric Delivery Programs
		[1]	[2]	[3]	[4]	[5]
Residential Unserved kWh Avoided	[a]	5,788,070	21,124,060	92,765	6,184,356	33,189,251
Residential VOLL per Unserved kWh	[b]	$0.92	$0.92	$0.92	$0.92	$0.92
Total Residential VOLL	[c]	$5,320,372	$19,417,155	$85,270	$5,684,636	$30,507,432
Commercial Unserved kWh Avoided	[d]	7,848,574	36,711,927	161,219	10,747,916	55,469,635
Commercial VOLL per Unserved kWh	[e]	$49.17	$49.17	$49.17	$49.17	$49.17
Total Commercial VOLL	[f]	$385,921,621	$1,805,159,294	$7,927,274	$528,484,920	$2,727,493,109
Industrial Unserved kWh Avoided	[g]	1,407,515	6,583,693	28,912	1,927,466	9,947,587
Industrial VOLL per Unserved kWh	[h]	$11.29	$11.29	$11.29	$11.29	$11.29
Total Industrial VOLL	[i]	$15,892,634	$74,338,243	$326,453	$21,763,531	$112,320,860
Total Customers Unserved kWh Avoided	[j]	15,044,160	64,419,680	282,896	18,859,737	98,606,473
Average VOLL per Unserved kWh	[k]	$27.06	$29.48	$29.48	$29.48	$29.11
Total Customer VOLL	[l]	$407,134,627	$1,898,914,692	$8,338,996	$555,933,087	$2,870,321,402

Sources and Notes:
[a], [d], and [g]: Table III-13 [a], [d], and [g] x 3
[b], [e], and [h]: See Table III-11
[c]: [a] x [b]
[f]: [d] x [e]
[i]: [g] x [h]
[j]: [a] + [d] + [g]
[k]: [l] / [j]
[l]: [c] + [f] + [i]
[5]: [1] + [2] + [3] + [4]

We adjusted the results presented in **Table III-13** for an assumed level of coincidence in the estimated future outages avoided by ES electric investments in **Table III-14**. It is equally unrealistic to assume that, following a future severe weather event, either none or all of the repairs for all of the failure modes addressed by the Electric ES sub-programs would occur during the exact same post-event hours. Instead, we employ a range we believe is realistic, namely two scenarios in which (a) 33% of the outage hours following a severe weather even are contemporaneous, thereby reducing the aggregate customer outage-hours by 33%; and (b) 50% of the outage hours reduced would have been contemporaneous, reducing actual net avoided outage-hours by 50%.

Table III-14
Estimated Unserved *Coincident* kWh (Avoided) and VOLLs
As Result Of Energy Strong Electric Delivery Investments
3-Day Outage

Coincidence Factor (%)	**Avoided CMI Outage** (million minutes)	**Avoided Unserved kWhs** (million kWh)	**Total Benefit to Customers** (2012$ millions)	**Break-Even CAIDI** (outage days)
[1]	[2]	[3]	[4]	[5]
Aggregate Non-Coincident	2,756	98.5	$2,870	2.06
33%	1,847	66.0	$1,923	3.08
50%	1,378	49.3	$1,435	4.13

Sources and Notes: *The Brattle Group @ 2013.*

Table III-14 shows that adopting a 33% coincidence factor, the net total CMIs saved as a result of PSE&G's Electric ES sub-programs would be about 1.85 billion minutes and customers would avoid roughly 66 million unserved kWh during this period. These saved CMIs and unserved kWh translate into a value to customers of approximately $1.9 billion. This is nearly $1 billion less than the comparable value to customers estimated on a non-coincident basis. If we employed a 50% coincident factor, which appears to be high, net total CMIs would be about 1.4 billion minutes during which almost 50 million kWh would go unserved with a value of $1.43 billion.

Thus, deployment of PSE&G's Electric ES sub-program would produce value to customers of roughly $1.9 billion over the course of widespread three-day outage assuming a 33% coincidence factor. This is almost equal to the PV of the entire Electric ES sub-program investment costs.[40]

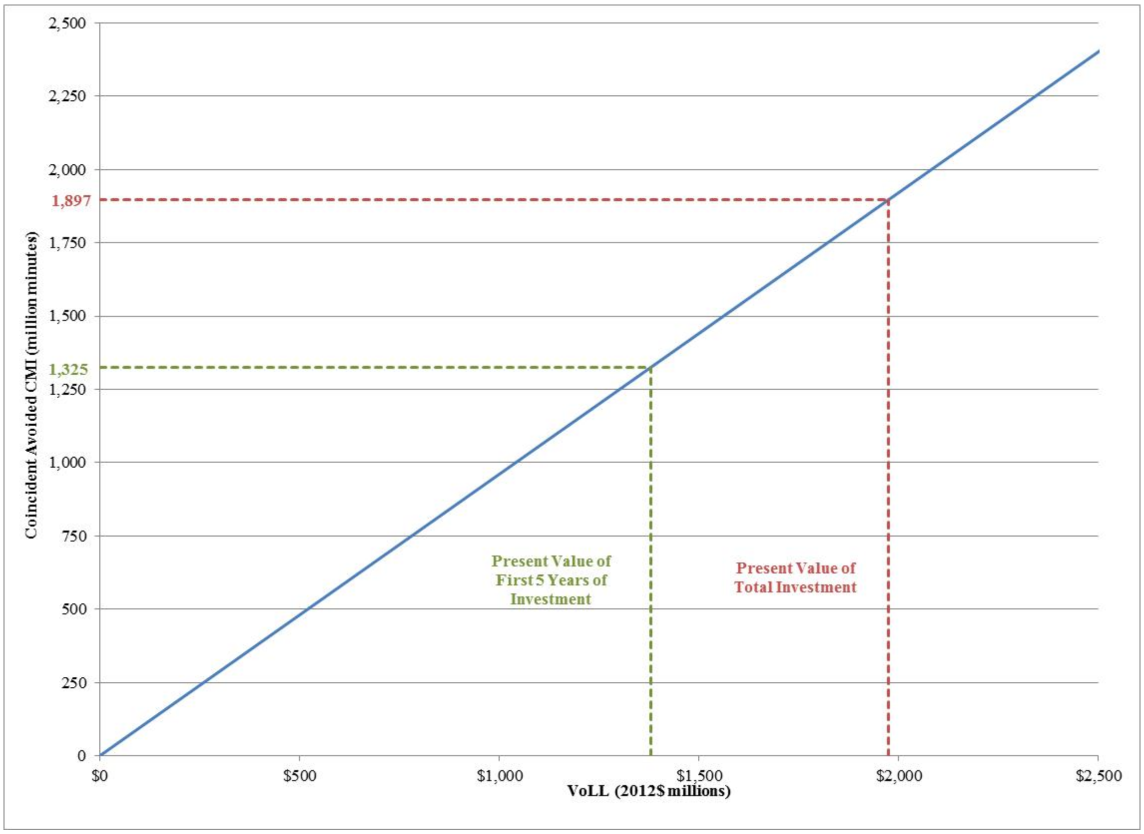
F. Break-Even Analysis

It is also informative to examine the PSE&G's Electric ES sub-program investments in terms of its "pay back," or the cumulative duration of avoided outages necessary for customers to realize value equal to the PV of investment cost. The total costs for PSE&G's Electric ES sub-program

[40] In comparing benefits to costs, we adopt the following simplified approach: We use the current year as the basis for estimating benefits associated with PSE&G's Electric ES sub-program investments. We compare the resulting benefits to the PV of investment costs. An alternative calculation would project a path of future benefits (which would grow over time), yet discount those future benefits to 2013 dollars using a social discount rate, in recognition of the fact that the avoided outages would relate to storms that happen at some unknown point in the next ten years. A reasonable estimate of the growth rate of future benefits might be based on Congressional Budget Office projections that imply an annualized real GDP growth rate of roughly 2.8% over the next 10 years (see http://www.cbo.gov/publication/43907); one commonly-used social discount rate is the U.S. Treasury Real Long-Term Rate, which is currently 1.01% (see http://www.treasury.gov/resource-center/data-chart-center/interest-rates/Pages/TextView.aspx?data=reallongtermrate). As long as the projected benefit growth rate is greater than the social discount rate, our approach of using only current-year benefits in assigning a value to avoided outages will result in a slight overestimate of the number of avoided outage days that would be needed to justify the investments. If, on the other hand, we were to project future benefits using the CBO numbers and discount them using the relatively high social discount rate of 4%, a simple net present value calculation reveals that the number of avoided outages needed to justify the investment is understated by at most 5%.

investments nearly \$2.8 billion, for a PV of nearly \$2.0 billion.[41] **Figure III-2** and **Figure III-3** demonstrate the levels of avoided CMI and unserved kWhs, respectively, that are needed to cover the PV of PSE&G's Electric ES sub-program costs.

Figure III-2
Total VOLL Dollar Value Vs. Customer Minutes of Interruption
"Break-Even" Analysis



Sources and Notes: *The Brattle Group @ 2013*

Figure III-2 shows the generally linear relationship between avoided and/or reduced coincident CMI and total VOLL dollars (recalling that coincident CMI can be translated into unserved kWh

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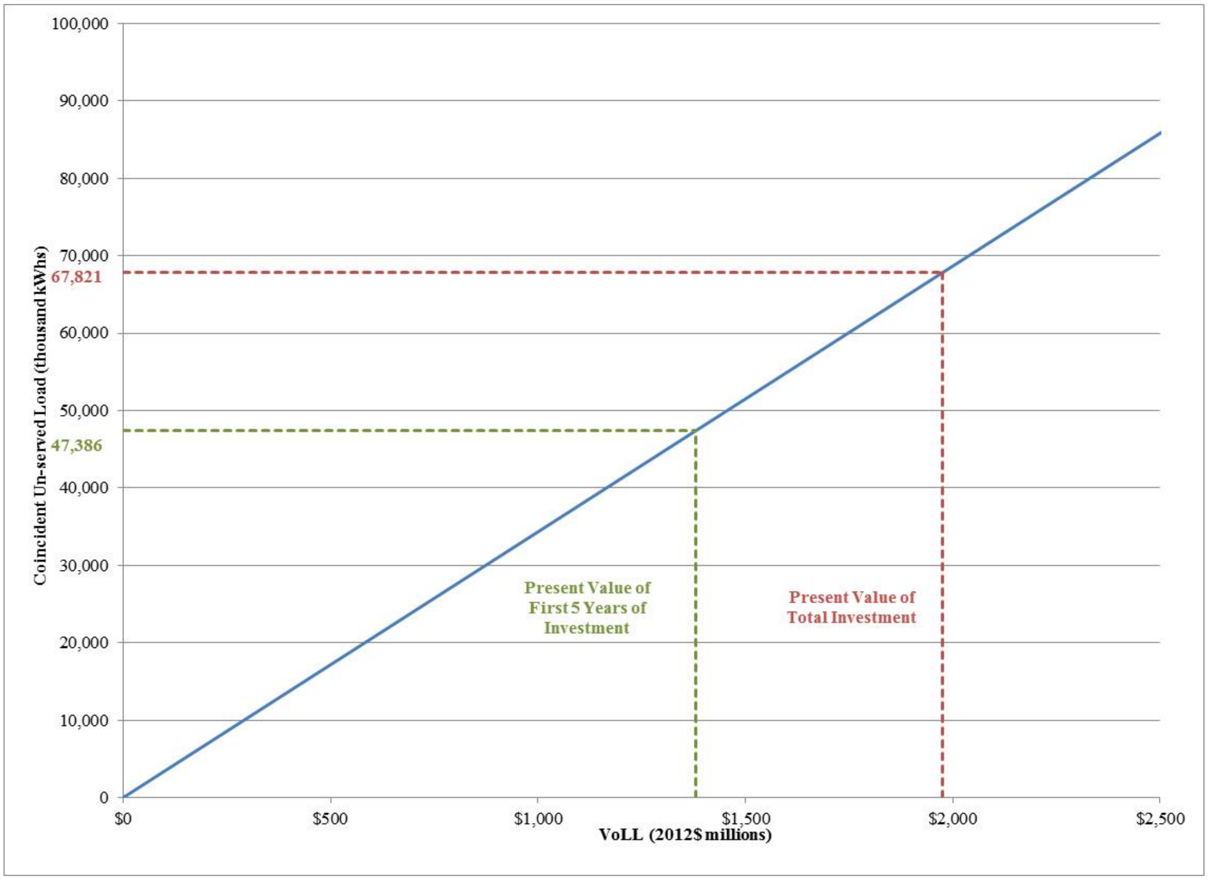
41 The first phase (months 1 - 60) of the Energy Strong program involving PSE&G electric delivery system is approximately \$1.7 billion in 2012 dollars, and has a PV of roughly \$1.4 billion, based on a discount rate of 7.01% as used by PSE&G in its Energy Strong filings with the NJ BPU. The program's second phase (months 61 – 120) is roughly \$1.1 billion in 2012 dollars, with a PV of approximately \$595 million. The analysis herein includes the entire expected cost of the Energy Strong program (*i.e.*, months 1 – 120). However, in its Energy Strong proposal, PSE&G is requesting the BPU to approve the first five years of the program only.

by taking customer mix and average load factor by customer class into account). **Figure III-2** indicates that PSE&G's Electric ES sub-programs would cover investment costs if PSE&G customers could avoid nearly 1.9 billion minutes (or about 31.6 million hours) of service interruptions on a non-coincident basis. These breakeven levels of outages would be less if additional benefit streams, such as social benefits in addition to the private benefits included in the VOLL estimates included herein, were considered.

A similar view is shown in **Figure III-3**, which compares the unserved (coincident) kWhs and total VOLL dollars.[42] The figure indicates that the electric delivery sub-program investments would "pay for themselves" (*i.e.*, cover the costs of investment) if PSE&G customers could avoid outages covering roughly 68 million unserved kWhs. Again, it is important to recall that these benefits reflect VOLLs only; they do not include other important and significant benefit streams, such as those associated with public safety.

[42] We apply a single unit VOLL value to each unserved kWh because nearly all of the electric delivery sub-programs proportionally affect residential, commercial and industrial, except for the Backyard Pole sub-program which affects only targeted residential customers.

Figure III-3
Total VOLL Dollar Value Vs. Coincident Unserved kWhs
"Break-Even" Analysis



Sources and Notes: *The Brattle Group @ 2013*

Such a break-even type analysis is informative because, as indicated in the figures, the total dollar VOLL value associated with the electric delivery sub-programs will largely be determined by the breadth and duration of prolonged outages. While a range of scientific studies strongly suggest that the frequency and amplitude of large storms will increase,[43] it is nonetheless unknowable how frequently and to what degree such events will affect PSE&G's service area. As discussed in Chapter I, the expected values of benefits cannot be estimated, because it is not possible to provide probabilities associated with specific outcomes (*i.e.,* the frequency and magnitude of major storms and the associated damage to the electric system).

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43 Ning Lin, Kerry Emanuel, Michael Oppenheimer, Erik Vanmarcke, "Physically based assessment of hurricane surge threat under climate change," Nature Climate Change, 2012.

Table III-14 previously shown in estimating the value to customers of avoiding a widespread three-day electric outage, also estimates the duration of outages needed for PSE&G's customers to realize value equal to the PV of the Electric ES sub-program costs. The table shows that these investments pay for themselves after customers experience an outage of only 2.06 days on a non-coincident basis and 3.08 days when a 33% coincidence factor is included. Specifically, this indicates that over the course of a widespread electrical outage lasting roughly 3.08 days, PSE&G's customers will experience outages totaling roughly 159 million hours[44], which translates into about 350 million kWhs going unserved. PSE&G estimates that its Electric ES sub-programs will reduce this duration by roughly 31.6 million hours, which will allow customers to be served by roughly 68 million kWhs; *i.e.*, these kWhs would have gone unserved except for the Electric ES sub-program investments. Thus, multiplying the "saved" kWhs for each customer class by the appropriate VOLL per unserved kWh provides an estimate of the value realized by customers as a result of PSE&G's Electric ES investments. We refer to break-even outage duration as the days of prolonged outages under which PSE&G's Electric ES sub-programs will save kWhs in sufficient quantity so that value received by customers is equal to the PV of the Electric ES investment costs.

PSE&G's Electric ES program, in total, appears to hold a high degree of economic merit when these break-evens of cumulative outage durations are compared to recent history. **Table III-15** summarizes the actual or coincident CAIDI (which estimates the average outage duration experienced by affected customers) statistics for outages associated with recent major weather events. PSE&G estimated that approximately two million customers were affected by outages caused by Superstorm Sandy, and the associated CAIDI for the Superstorm Sandy event to be 3.36 days.

44 Calculated as the product of the hours of outage experienced by PSE&G customers in a hypothetical 1 day outage (51.7 million hours) times 3.08 days, which equals 159 million hours.

Table III-15
Summary of PSE&G 2011 and 2012 Major Outages
Customers, CMI and CAIDI*

Major Events and Dates		**2011** CMI (million minutes)	**2011** Customers Affected	**2011** CAIDI (days)	**2012** CMI (million minutes)	**2012**	**2012** CAIDI (days)
		[1]	[2]	[3]	[4]	[5]	[6]
Event 1	2/2/2011	10.2	57,430	0.12	-	-	-
Event 2	7/22/2011	9.9	83,827	0.08	-	-	-
Event 3	7/29/2011	14.0	59,140	0.16	-	-	-
Event 4 - Hurricane Irene	8/27/2011 to 9/1/2011	1,002.4	841,467	0.83	-	-	-
Event 5 - October Snow Storm	10/29/2011 to 11/4/2011	835.7	616,641	0.94	-	-	-
Event 6 - Superstorm Sandy	10/27/2012 to 11/14/2012	-	-	-	9,750	2,013,974	3.36
Total Major Events		1,872	1,658,505	0.78	9,750	2,013,974	3.36

Sources and Notes:
* Because these figures are actual historic experience, they reflect actual coincidence of outage failure mode repairs
[1] and [4]: See Table III-2.
[2] and [5]: PSE&G IEEE Storm Outage Data.
[3]: [1] * 1,000,000 / [2] / 1440.
[6]: [4] * 1,000,000 / [5] / 1440.

The break-even outage duration of 3.06 days on a coincident basis also appears to provide strong justification for deploying the Electric ES program when other severe weather events are considered. Specifically, only a few weather events of severities equal to that of Hurricane Irene and/or the October Snowstorm (which both occurred between late August and early November 2011, and had CAIDIs of 0.83 days and 0.94 days, respectively) would need to be experienced over the next 10 years in order for the value of avoided outages to customers to cover the PV of the Electric ES sub-program costs.

IV. ENERGY STRONG – GAS

A. PSE&G Gas System Performance

Natural gas distribution systems are less vulnerable to the failure modes that affect electric systems, including widespread cascading failures. However, gas customers can and do experience outages due to localized piping breaks, meter failures, water ingress in local mains and/or system-wide failures involving the loss of pressure due to large-scale disruptions. Failures in piping or meters affect individuals or small groups of customers, while the remainder of the system operates as usual. On the other hand, a failure in a gas main can cause an outage for dozens to hundreds of customers and often requires a longer repair and restoration period than a single failure. However, even under these circumstances, the overall system maintains its pressure and function. It is possible that leakages and/or disruptions to a sizable portion of the gas grid becomes so impaired that the entire grid section is shut down, and then needs to be repaired, and re-pressurized – although such widespread forced outages are infrequent. In addition to repairs to the system, each customer premise that is affected by an outage must be inspected, frequently a lengthy and costly process, before service can be restored.

Gas distribution systems typically do not keep outage statistics that are analogous to the reliability metrics tracked by electric utilities (*i.e.,* SAIDI, SAIFI and CAIDI). However, PSE&G tracks gas outages by cause for normal and severe weather situations. **Table IV-1** shows the number of instances in which PSE&G had to respond to a water infiltration problem in their gas system between 2003 and 2012; it also shows the average duration of and hours involved in repairs.

Table IV-1
Historical Water Infiltration Instances on UP Distribution System

Year	# Instances	Significant Weather Event	Total Hours	Avg. Hrs/Instance
	[1]	[2]	[3]	[4]
2003	268		6,557	24.5
2004	15		547	36.5
2005	13		955	73.5
2006	900		7,899	8.8
2007	1,139	x	14,992	13.2
2008	787		10,351	13.2
2009	816		12,421	15.2
2010	958	x	14,467	15.1
2011	1,578	x	20,080	12.7
2012	1,109	x	8,757	7.9
Total	7,583		97,026	12.8

Sources and Notes:
[1], [3], and [4]: See RCR-G-POL-45, Answer (b)
[2]: Significant Weather Events based on RCR-G-POL-51

The table also highlights (in column 2) the instances in which severe weather triggered significant outages. As indicated, water infiltration in the gas system are exacerbated by severe weather, but water infiltration problems also occur as a result of less severe (*i.e.*, not "named") storms, albeit to a lesser extent.

Table IV-2 summarizes the number of customers that experienced interruptions to their gas services as a result of the major weather events indicated in **Table IV-1**. That is, it shows the gas customers impacted from storms occurring in 2007, 2010, 2011 and 2012.

Table IV-2
Number of PSE&G Gas Customers Impacted
During Severe Weather Events

Event	Date	Number of Customers Impacted
		[1]
Nor'easter	April 2007	10,076
Nor'easter	March 2010	2,615
Hurricane Irene	August 2011	12,712
Tropical Storm Lee	September 2011	1,547
Superstorm Sandy	November 2012	6,808

Sources and Notes: RCR-G-POL-51
[1]: Refers to the number of customers in which the storm prevented the continuation of safe gas service, so service had to be shut-off until repairs were completed.

As indicated in the table above, approximately 6,800 customers lost service due to customer gas meter failures, and flooding occurred in the gas system in 25 municipalities within PSEG's service area during Superstorm Sandy. Of these, approximately 1,100 customers lost service due to water ingress into UPCI mains.[45] The average outage durations for individual customers affected by this storm was roughly four days, with maximum customer outage durations extending to eight days for some PSE&G gas customers[46] Outages caused by the storm also necessitated roughly 41,500 buildings to be inspected during and/or after the storm.

B. Gas ES Investments

There are two primary Gas ES investments that benefit PSE&G's customers:

- Hardening nine of PSE&G's metering and regulation (M &R) stations and the Burlington LNG and LPG storage facilities; and

45 S-PSEG-ES-46 ii.

46 S-PSEG-ES-46 iii.

- Replacing utilization-pressure cast iron (UPCI) mains[47] and 40,000 steel service pipes in municipalities with records of flooding, and installing excess flow valves (EFVs) wherever services are replaced for single family dwellings.

Table IV-3 shows the outlay profile for the two Gas ES investment sub-programs, totaling $906 million for the first five years and $1.18 billion for the entire effort. The combined investment costs of relocating the targeted M&R stations plus improving back-up power arrangements to the Burlington storage facilities are approximately $140 million or about 12% of the total proposed ES gas investments. PSE&G's proposed UPCI investments constitute the majority of the gas ES program, costing roughly $1.04 billion or about 88% of total ES gas program costs.

Table IV-3
Gas Energy Strong Investments
Summary of Total Investment Costs

		Proposed Investment (2012$ millions)					
		Investment: Months 1 - 60		Investment: Months 61 - 120		Total Investment	
Gas ES Sub-program	**Description**	**$**	**%**	**$**	**%**	**$**	**%**
Metering & Regulating Station Flood and Storm Surge Mitigation	Raise, rebuild and/or install floodwalls at nine M&R stations, following newly defined FEMA/NJ DEP flood elevation data. Also includes flood mitigation and back-up power at Burlington LNG plant and Harrison LPG peak shaving plant.	$76.00	8%	$64.00	23%	$140.00	12%
Utilization Pressure Cast Iron (UPCI)	Replace exiting UPCI main and associated district regulators with plastic or coated cathodically protected welded steel. Replace with high pressure and abandon regulators where feasible – 750 miles	$830.00	92%	$210.00	77%	$1,040.00	88%
Total		$906.00	100%	$274.00	100%	$1,180.00	100%

Source: PSE&G Petition for Approval of the Energy Strong Program, February 20, 2013

Gas ES Sub-program 1: M&R Stations. This sub-program is aimed at mitigating risks associated with station flooding and storm surges. PSE&G's M&R stations were generally considered to be in storm-safe locations. However, nine of PSE&G's these stations were either impacted by Superstorm Sandy or are located within newly defined FEMA flood zones.

PSE&G's gas system is an interconnected mesh system, and its M&R stations serve the entire gas system rather than isolated segments. However, it is reasonable to view the reliability benefits of these investments as more concentrated in the portions of the gas system that are

[47] Utilization Pressure is approximately 0.25 psig; the remainder of PSEG's distribution system operates at 15 or 60 psig. RCR-G-ENG-8.

closer and directly connected to these stations. Within these affected portions of the PSE&G system, all classes of customers receive roughly equal benefits in terms of reduced risk and reduced outage probabilities.[48]

PSE&G calculated the number of customers associated with each M&R station by allocating PSE&G's total customer numbers in proportion to design day flow. The customers served by the various PSE&G M&R stations are included in **Table IV-4**, which summarizes PSE&G's estimates and shows each station's percentage of total system design-day flow as well as the numbers of residential, commercial and industrial customers served by each station.[49]

Table IV-4
Summary of Customers Affected By M&R Station Upgrades

M&R Station	Share of Total System Flow	Residential	Commercial	Industrial
	[1]	[2]	[3]	[4]
Brooklawn	1.05%	16,941	1,586	72
Burlington-LNG	2.47%	39,730	3,718	169
Camden	1.38%	22,204	2,078	95
E Rutherford	8.38%	134,799	12,616	574
Harrison	9.98%	160,544	15,026	684
Paterson	1.90%	30,561	2,860	130
Newark Airport	0.53%	0	64	15
Westend	8.93%	143,666	13,446	612
Crown Central	-	-	-	-
Piles Creek	-	-	-	-
		548,445	51,394	2,351

Sources and Notes:
[1]: PSE&G of percent of total system gas flow through M&R station
[2]: [1] x 1,608,466 Residential Gas Customers
[3]: [1] x 150,539 Commercial Gas Customers
[4]: [1] x 6,850 Industrial Gas Customers
Newark Airport customer estimates from PSE&G
* Crown Central and Piles Creek stations supply PSE&G's gas transmission system and indirectly supply the gas distribution system.

48 The ES Gas investments are primarily targeted at avoiding outages. They are not aimed at reducing the duration of outages should they occur, as is the case with some of the ES Electric investments. See RCR-G-POL 26.

49 Affected customers include all relevant PSE&G customers, including non-firm gas customers. We exclude the value of gas service to interruptible customers in further analysis below, which we consider to be a conservative assumption because interruptible customers may lose some (or even all) of the value of gas service when service is interrupted for a prolonged period.

Gas Storage Facilities. PSE&G owns one liquid natural gas (LNG) storage facility and three liquid propane gas (LPG) peaking facilities to supplement its pipeline gas supplies when demand on its system peaks, typically on very cold winter days. The locations and daily send-out capacities of these facilities are shown in **Table IV-5**. The Burlington plant is forecast to provide approximately 64.4 MDth (*i.e.*, 64.4. x 1000 decatherms) and the LPG plants together are expected to provide about 197.3 MDth on the peak day of the next several years.

Table IV-5
PSE&G's LNG and LPG Plant Characteristics

Plant	Location	Daily Capacity (Therms)
Burlington LNG	Burlington, NJ	670,500
Camden LPG	Camden, NJ	320,000
Harrison LPG	Harrison, NJ	900,000
Total		1,890,500

Source: PSE&G's 2012 10-K (March 8, 2012), page 37.

These facilities were either exposed to flooding during Superstorm Sandy and/or lost their secondary power supplies due to the impacts of the storm. The Harrison LPG plant was out of service for seven days during Superstorm Sandy. Fortunately, these were days in which the plant was not needed.[50] Also, the Burlington LNG plant lost its secondary power twice, first on October 29, 2012 for a period of over three hours and again later that day for a period of almost a full day (from 8:55 pm that evening through 5:55 pm on October 30th).[51] The proposed Gas ES investments would create a secondary power source well above the expected levels of flooding to operate these facilities located onsite.

PSE&G estimates that the repair period for these facilities, should they become damaged by a severe weather event, is between 6 and 18 months.[52] Having its LNG and LPG peaking facilities

50 S-PSEG-ES-42.

51 PSEG RCR-G-POL-37.

52 RCR-G-ENG-9.

off-line would have significant consequences. Most notably, PSE&G would need to purchase additional peak supplies (from other gas providers) in order to replace its off-line peaking capacity, assuming that such supplies were available on short notice. This could prove to be costly or be unsuccessful. For the purposes of our analysis we assume that, should these facilities be forced to go off-line, PSE&G would be able to procure alternate resources and, thus, PSE&G's customers would suffer no outages in their gas services.[53] We consider this to be a very conservative assumption, as severe weather may well occur near peak sendout days, which may coincide with market unavailability of peak supplies.[54] In addition, outages triggered by severe weather are quite likely to span at least one entire heating season.

Gas ES Sub-program 2: UPCI. This sub-program involves the replacement of approximately 750 miles of utilization pressure cast iron (UPCI) pipe and the associated approximate 40,000 unprotected steel services pipes on the PSE&G gas distribution system. This sub-program is aimed primarily at reducing leakage and leak potential in aging cast iron pipes and reducing the risk of water ingress, especially in flood zones or tidal surge areas.[55] PSE&G operates 4,753 miles of UPCI mains, 77% of which are cast iron. About 470 miles of mains of all types (but predominantly cast iron) are located within or near flood zones.[56]

PSE&G estimates that the UPCI replacement investment will eliminate essentially 100% of the outages due to water infiltration in the upgraded system.[57] Furthermore, PSE&G estimates that the UPCI upgrade will prevent approximately 800 leaks per year, including roughly 90 leaks which involve cast iron main breaks.[58] Excess flow valves (EFVs) will also be added when the

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[53] However, in the event of a loss of PSE&G's LNG facility for an entire heating season, customers in the vicinity of the LNG plant would likely experience outages as a result of constraints in the gas distribution system.

[54] This could occur from a variety of causes, including insufficient available supplies, insufficient time to make arrangements, or damage to the providers of peak gas from the same weather event that reduced LNG and LPG supplies.

[55] About 470 of the 750 miles of UPCI are directly within the flood zones. RCR-G-POL-42.

[56] RCR-G-POL-42.

[57] S-PSEG-ES-1.

[58] S-PSEG-ES-46 (g).

service pipes are replaced, and district regulators (located in the areas of UPCI replacement) will be eliminated, which will reduce susceptibility to flooding. Upgrading this portion of PSE&G's gas system will also have an impact on the quantity of gas lost and emissions of methane.

The replacement of cast iron pipes also addresses safety concerns associated with a higher risk asset. These pipes are at greater risk of leaking, even under normal conditions. The risk of leaks from plastic or cathodically protected steel pipes is lower and the risk of damages is much lower for homes with EFVs installed. We do not include these very significant safety related benefits in our calculations.

PSE&G's UPCI sub-program primarily affects PSE&G's residential customers; the company estimates that only about 2% of customers connected to the upgraded pipelines are (smaller) C&I customers. To be conservative, we assume that the UPCI sub-program does not benefit C&I customers who, as discussed earlier in this report, place higher values of avoiding the loss of gas service than do residential customers.

C. COSTS AND BENEFITS

PSE&G engineers estimate that the Gas UPCI sub-program will directly benefit 62,748 of its gas customers and that the M&R station sub-program will directly benefit 602,189 gas customers. The breakdown of affected customers is provided in **Table IV-6.**

Table IV-6
Summary of Customers Affected by Gas ES Investments

	PSE&G Gas Customers			Customers Affected By:	
	Gas Only Customers	**Gas and Electric Customers**	**Total Gas Customers**	**Sub-program 1: M&R Stations**	**Sub-program 2: UPCI + Services**
	[1]	[2]	[3]	[4]	[5]
Residential	294,301	1,314,165	1,608,466	548,445	62,748
Commercial	42,300	108,239	150,539	51,394	NA
Industrial	2,383	4,467	6,850	2,351	NA
	338,984	1,426,872	1,765,856	602,189	62,748

Source and Notes:
[1] and [2]: See Table I-1
[3]: [1] + [2] [4]: See Table IV-4
[5]: S-PSEG-ES-46

Gas outages tend to be less frequent than electric outages, and storm related outages are typically less extensive for gas customers than is the case for electric outages. However, when gas outages do occur, they tend to have longer durations than electric outages. We estimated the value to customers that PSE&G's Gas ES sub-programs would provide to them if they were to prevent a five day outage in their gas service, as is shown in **Table IV-7**.

Table IV-7
Gas ES Investment Value to Gas Customers
of Five Day Outage

		Gas ES Sub-program 1: M&R Stations	Gas ES Sub-program 2: UPCI + Services
		[1]	[2]
Customers Affected			
Residential	[a]	548,445	62,748
Commercial and Industrial (C&I)	[b]	53,745	0
Value of Natural Gas Service ($ per customer per day)			
Residential Value of Lost Service	[c]	$53	$53
C&I Value of Lost Service	[d]	$1,775	$1,775
Value of Avoiding 5-Day Outage ($millions)	[e]	$624	$17
Total Benefits ($millions)	[f]	$640	

Source and Notes:
[1a] and [1b]: See Table IV-4
[2b]: See Table IV-6
[e]: {([a] x [c] x 5) + ([b] x [d] x 5)} / 1,000,000
[f]: [1e] + [2e]

As shown in the table, avoiding a five-day outage in gas service is worth approximately $640 million to the customers who receive the benefit (in terms of avoided outages) from PSE&G's Gas ES investments.

As was the case in our analysis of PSE&G's Electric ES investments, we find that a break-even of cumulative outage duration of gas outages so that the value of avoiding outages to customers to be equal to the cost of PSE&G's Gas ES investments to be more informative to policy makers because a break-even analysis does not rely on a single point assumption concerning outages. The break-even analysis for PSE&G's Gas ES investment is summarized in **Table IV-8**.

Table IV-8
Gas ES Investment Break-Even Analysis

		Gas ES Sub-program 1: M&R Stations	Gas ES Sub-program 2: UPCI + Services
		[1]	[2]
Gas ES Program Costs ($millions)			
Investment Cost	[a]	$140	$1,040
Present Value	[b]	$100	$807
Customers Affected			
Residential	[c]	548,445	62,748
Commercial and Industrial (C&I)	[d]	53,745	0
Value of Natural Gas Service ($ per customer per day)			
Residential Value of Lost Service	[e]	$53	$53
C&I Value of Lost Service	[f]	$1,775	$1,775
Benefits = Present Value of Cost (outage days)	[g]	0.80	240.35
Overall Gas ES Break-Even (outage days)	[h]	7.08	

Source and Notes:
[a] and [b]: See Table IV-3
[1c] and [1d]: See Table IV-4
[2c]: See Table IV-6
[e] and [f]: See Table II-3
[g]: [b] x 1,000,000 / ([c] x [e] + [d] x [f]), performed separately for columns [1] and [2]
[h]: Same calculation as [g], including both columns [1] and [2]

The table indicates that overall the benefits realized by PSE&G's affected gas customers would pay for the investment cost of the company's Gas ES sub-programs if the sub-programs could prevent 7.08 days of gas outages for these customers. The benefits to customers affected by the Gas ES investments involving hardening the M&R stations would cover the associated investment costs if the sub-program could reduce the cumulative duration of gas outages by 0.8 days.

The cost of the proposed UPCI investment program is considerably higher than that associated with the M&R stations, and the vast majority of affected customers are residential, who (as discussed in Chapter II) place lower values upon avoiding gas outages than do commercial and/or industrial customers. Thus, as indicated in the table, a high cumulative duration of gas outages are required for residential customer value (of avoiding outages) to equal the PV of investment cost. There are, however, several other benefits associated with the Gas ES program that are not included in this analysis. As detailed below, there are environmental benefits associated with the UPCI investment program, and our analysis does not quantify the benefits of increased employment associated with construction and deployment of ES investments. In addition, as also discussed below, replacing cast iron and/or unprotected steel piping with plastic or protected steel and EFVs greatly improves public safety concerns, the benefits of which can be measured as reducing the risk of damage to property and human life.

D. Additional Benefit: Methane Reduction

The UPCI sub-program involves replacing about 750 miles of utilization-pressure distribution main and 40,000 steel service pipes. In addition to a primary goal of making PSE&G's gas system less likely to suffer water ingress (as a result of the higher operating pressures used with the new pipes), the replacement pipes will be much less susceptible to leaks. Reducing pipe leakage provides additional benefits to PSE&G's customers, and the populace in general. First, lower levels of gas leaks provide public safety benefits; gas leaks can combust and cause damage to life and property. Second, natural gas leaks have a direct cost to customers because the volumes of gas are included in PSE&G's revenue requirement (even though the gas is not consumed) and ultimately paid for by customers.

Third, leakage natural gas (methane) is a potent greenhouse gas. The cost of greenhouse gas emissions can be estimated by applying a "carbon price" to "tons of CO_2-equivalent", which can further be valued in dollar terms at a specified carbon price or value. **Table IV-9** summarizes our calculation of the impact PSE&G's Gas ES investments are expected to have on reducing methane emissions.

Table IV-9
Gas ES Program Impact on Methane Leakage

Natural Gas Pipeline Type	Natural Gas Pipeline Material	Gas ES Program Impact (miles of pipeline or lines of service)	Methane Emission Factor (mscf per mile-year or mscf per service-year)	Program Impact on Methane Emissions (mscf per year)	Program Impact on Carbon Emissions (short tons CO_2-equivalent per year)
		[1]	[2]	[3]	[4]
Main	Steel/Unprotected/Bare	0	110.19	0	0
Main	Steel/Cathodically Protected/Coated	20	3.12	62	28
Main	Plastic Pipe	730	19.30	14,089	6,281
Main	Cast Iron, Wrought Iron	(750)	238.70	(179,025)	(79,815)
Service	Steel/Unprotected/Bare	(40,000)	1.70	(68,000)	(30,316)
Service	Steel/Cathodically Protected/Coated	0	0.18	0	0
Service	Plastic Pipe	40,000	0.01	400	178
Service	Cast Iron, Wrought Iron	0	0.00	0	0
Total Program Impact on Emissions				**(232,474)**	**(103,644)**

Source and Notes:
[1] and [2]: PSE&G data
[3]: [1] x [2]
[4]: ([3] x 42.46 / 2000) x 21

The table indicates that, based on leakage rates developed by the U.S. Environmental Protection Agency, the Gas ES investments should reduce methane emissions by over 230 thousand cubic feet per year.

Table IV-10 summarizes the costs associated with leakage of natural gas. The table shows that unaccounted-for-gas costs PSE&G and its gas customers about $1.0 million per year. Furthermore, the table indicates that assuming a carbon value of \$46/tCO_2-e in 2012 dollars, the total "carbon cost" avoided by replacing these older pipes is approximately $4.7 million per year. The sum of the unaccounted-for-gas costs and carbon costs is approximately $5.7 million per year.

Table IV-10
Quantified Benefits from Leakage Prevention

Reduction in Methane Emissions (mscf per year)	Price of Methane ($ per mscf)	Avoided Cost of Methane Loss ($ per year)	Reduction in Carbon Equivalent Emissions (short tons CO2-equivalent per year)	Price of Carbon ($ per CO_2e)	Avoided Cost of Carbon Equivalent Emissions ($ per year)
[1]	[2]	[3]	[4]	[5]	[6]
232,474	$4.39	$1,021,116	103,644	$45.50	$4,715,855

Sources and Notes:
[1]: see Table IV-8
[2]: PSE&G's 2013/2014 Annual BGSS Commodity Charge Filing, Section 2, Item 2.
[3]: [1] x [2]
[4]: see Table IV-8
[5]: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis, May 2013; Based on 2020 value at 3% discount rate; increased to 2012$ based on 8.6% inflation between 2007 and 2012 according to BEA (http://www.bea.gov/national/pdf/nipaguid.pdf) and converted to short tons at factor of 0.91 short tons to 1 metric tonne.
[6]: [4] x [5]

V. SUMMARY AND CONCLUSION

The preceding analysis of PSE&G's ES program focused primarily on the benefit streams associated with the values that consumers place upon mitigating prolonged outages; it largely excluded consideration of a variety of other areas of benefits. These latter areas notably include: benefits to the public (*e.g.*, continued access to essential services during times of power outages and heightened safety concerning gas services), benefits in the form of employment (associated with construction and deployment of ES investments) and mitigation of lost tax and other public revenues. These types of benefits are both important and significant; excluding them from our analysis should not suggest that they are secondary to the scope of the benefit stream analyzed in this report.

Our analysis provides indications of 1) the value that PSE&G's customers can expect to realize following representative prolonged outages in electric and gas services resulting from severe weather events, and 2) the "break-even" cumulative duration of outages that customers would need to experience which, if avoided, would create value to customers equal to the PV of PSE&G's proposed ES investment program. The break-even analyses provide an indication of how many such major weather events need to be experienced before customers realize value sufficient to "pay for" PSE&G's investments in the ES program.

Our analysis does not provide an indication of the *expected values* of benefits. Estimates of future outages that will be avoided and/or reduced are highly uncertain because the ES program is targeted toward combatting the effects of severe storms, which may or may not occur, and have highly variable levels of severity and geographic impacts when they do occur. Thus, it is not possible to estimate a mean or future expected value of the benefits stemming from PSE&G's ES investments without specifying the probability distribution of severe weather events affecting PSE&G's customers in the future. These probabilities are not presently available.

A. Value Analysis

Estimating the value to PSE&G customers of avoiding losing electric and/or gas service necessarily involves the adoption of a range of assumptions, including the effectiveness of the ES program investments in mitigating service outages and the value that customers place upon avoiding service interruptions. We developed a Base Case value analysis which reflects a three-day widespread outage in electric service and a five-day widespread outage in gas service. Also, for this case, we applied the VOLL per unserved kWh based on the median values for commercial electric customers (as discussed in detail in Chapter III) and the average values for residential and C&I gas customers (as discussed in Chapter IV).

PSE&G was able to apply its engineering expertise and considerable data base of system outages and causation to approximate the specific impacts that the various Electric ES sub-programs will have on customer outages. These data provided context from which to approximate the duration of recent prolonged outages such as those experienced following Superstorm Sandy and Hurricane Irene. We applied the VOLLs developed in Chapter III to the electric customers that PSE&G estimated would be affected by a widespread outage in order to estimate the dollar benefits to customers of avoiding such an outage. We estimated the non-coincident sum of the benefits (in terms of avoided and/or reduced outages) for each of the Electric ES sub-programs to be roughly $2.9 billion.

In practice, however, customer outages actually experienced would be less than this sum because a major weather event may not impact all of the points of failure addressed by the ES program or, if multiple points do fail, PSE&G's restoration efforts may be undertaken on parallel paths. In that way, the outage duration experienced by customers is less than if restoration efforts were conducted serially. We applied factors which generally account for outage "coincidences." We assumed that the actual outages experienced by customers would be 33% to 50% less than the summed outage durations above. This reduced the non-coincident estimate of benefits above to roughly $1.9 billion (assuming a coincidence factor of 33%).

PSE&G customers have experienced limited outages in gas service as a result of severe weather, but recent changes in flood and tidal surge zones have led the company to expect additional challenges to their gas system infrastructure in the future. PSE&G estimated the number of gas customers who will be affected by its Gas ES investments. Outages in gas service are typically less frequent than outages in electric service, but tend to be of longer duration when they occur. Accordingly, for purposes of this value analysis, we assumed an outage duration of five days. The resulting estimate of value to customers from avoidance of such cumulative outage was approximately $640 million in the Base Case.[59]

Finally, in estimating the Base Case value that PSE&G customers place upon avoiding service interruptions, it is important to recognize that PSE&G serves 57% of its customers on a combined basis (*i.e.,* customers who receive both electric and gas service). Those customers incur costs and/or lose value because they are unable to remain in their residences and/or are unable to carry on production and business. The impact on customers (in terms of lost value) from outages in both electric and gas services probably exceeds the impact of losing only one service but is likely less than the additive effect of the values lost separately for electric and gas service. We adjust for the impact of PSE&G customers that receive combined electric and gas service upon our value calculations. Following this, we estimate that the value that customers place on mitigation the loss of electric and gas services is roughly $3.15 billion, instead of the sum of the values to customers as calculated in our Base Case (*i.e.*, approximately $3.5 billion).

B. Break-Even Analysis

The value analysis discussed above is informative because it expresses benefits to customers within the context of reasonable bounds of outage durations, especially with respect to PSE&G's recent history of outages in electric service. However, it is based on a single outage duration which, as discussed above, is unknowable. We conducted a break-even analysis for the Electric and Gas ES sub-programs in order to estimate the cumulative outage durations that would need to be experienced by PSE&G customers which, if mitigated, would create value to customers equal to the PV of PSE&G's proposed ES investment program.

We estimated that PSE&G's electric customers would need to realize avoided and/or reduced outages of roughly 3.08 days as result of the company's deployment of its Electric ES sub-

[59] The Gas Base Case includes the following assumptions: 1) values per unserved day as discussed in Chapter II and used in Chapter IV, and 2) cumulative gas service outage duration equal to five days.

programs in order to accrue value sufficient to equal the PV of the associated investments. The break-even for PSE&G's Gas ES sub-programs, estimated to be roughly 7.08 days is slightly higher than that for the Electric ES.

The break-even outage that we estimated is cumulative, which means that numerous permutations of storm related events over the course of the life of the ES assets (which are generally longer than the 10 year ES investment period) can produce 3.08 days of outages in PSE&G's electric system and/or 7.08 days of outages in PSE&G's gas system. For example, a single event, such as Superstorm Sandy, which caused outages across nearly the entire PSE&G electric system, or a series of lesser storms that cause outages of less than 24 hours can result in customer outages that add up to 3.08 days of system-wide outage equivalents. Furthermore, these major outages can take place over the life of the assets associated with PSE&G's Electric ES investments, which varies depending on the specific assets involved but generally will greatly exceed the 10 year ES investment period.

The Electric and Gas ES sub-programs span a range of investment areas. Some of these sub-programs address centralized investments that cover large groups of customers,[60] while other areas of infrastructure hardening cover individual circuit or relatively small groups of customers. The investments that cover broader groupings of customers tend to have lower break-evens in terms of outage durations (*i.e.,* fewer days of outages) than do investments that are aimed at individual circuits and/or customers, simply because investments in circuits or gas piping are "paid for" by few customers. Thus, more outage hours by a relatively few customers that are affected by the ES investments are needed to cover the PV of the investments aimed at individual circuits and/or customers. This observation is far from unique when analyzing infrastructure investments. In fact, it exemplifies the nature of completing "last mile" infrastructure upgrades; *i.e.*, lines and pipes that connect individual customers to more centralized areas of investment.

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[60] For example, Electric Substation Flood and Storm Surge Mitigation (Sub-program 1 under Electric Delivery Infrastructure Hardening Investments) and Gas Metering and Regulating (M&R) Station Flood and Storm Surge Mitigation (Sub-program 1 under Gas Delivery Infrastructure Hardening Investments) involve stations that feed wide groups of customers.

Most of the differences in break-even outage durations across sub-programs can be explained by the customer base that benefits from the investment. The PSE&G Electric ES sub-programs that address individual circuits and/or customers have a longer break-even outage duration, but are nonetheless a critical part of mitigating the effects of severe weather. Likewise, PSE&G's Gas ES sub-programs requires a longer duration of outages to reach break-even because much of the overall investment involves the relatively expensive replacement of piping that serves the residential market. Specifically, with respect to the Gas ES sub-programs, PSE&G's flood and tidal surge mitigation sub-program for targeted M&R stations had a relatively short break-even outage duration (0.88 days). On the other hand, PSE&G's UPCI sub-program provides direct benefit almost exclusively to the residential customers who reside on or near the gas system's older cast iron and unprotected steel. Taking into account only those direct benefits, the lower level of value realized by residential customers (when compared to the comparable value of avoiding gas outages for C&I customers) results in a much higher break-even of outage duration than is the case for the M&R sub-program. Other benefit streams, not included in our analysis here, may fill some or all of this gap.

C. Range of Benefits

Our estimates of the value to customers resulting from PSE&G's ES investments are, of course, based on the assumptions that we stated and explained throughout our report. There is no guarantee that our estimates will match actual results, even if modified our assumptions to allow for a wider range of outcomes. Changes in many factors over the course of the life of the ES assets, including climate issues, demographics and/or alternative technologies, may significantly influence the ultimate benefits that PSE&G customers realize. Nonetheless, we modified our assumptions to test the sensitivity of our estimates to key assumptions.

We identified one assumption parameter, VOLL per unserved kWh for commercial customers, as a key variable that can have a significant impact upon total benefit calculations. Accordingly, we varied this variable upward and downward. As discussed in Chapter II, we found that the VOLL estimates for electric customers and VOLL-equivalents for gas customers were generally consistent. However, we observed that VOLL for electric C&I customers (on a daily basis) was notably higher than the equivalent value-added for C&I establishments in New Jersey. We recalculated the benefits to customers of avoiding the loss of electric service using two additional VOLLs per unserved kWhs for commercial customers: 1) based on the predicted VOLLs for commercial customers (as reported in the Berkeley study); and, 2) setting the VOLL per unserved kWh for commercial customers equal to the VOLL measure for industrial customers.

We also considered the sensitivity of the assumptions used in estimating the benefits associated with PSE&G's Gas ES sub-programs. However, we did not alter the values per day of losing gas service for residential and C&I customers in developing a range of benefits.

Table V-1 summarizes the range of values to customers of avoiding and/or reducing interruptions in their electric and gas services. The table shows that the value to electric customers ranges from \$769 million to \$17.6 billion on a non-coincident basis and from \$515 million to \$11.8 billion on a coincident basis. The difference between the high end of this range and the point estimates are attributable exclusively to the substitution of the VOLLs per unserved kWh for commercial customers as reported in the Berkeley study. We find the high-end estimate to be plausible but, as discussed in Chapters II and III, suspect that outlier survey responses included in the Berkeley study may drive VOLLs for commercial customers higher than should be used in a study for New Jersey.

Table V-1
Summary of Value Analysis
($millions)

		Coincidence Factor	
		Aggregate Non-Coincident	**33%**
		[1]	[2]
Electric - As-Published Berkeley VOLLs	[a]	$17,595	$11,788
Electric - Median Commercial VOLLs	[b]	$2,870	$1,923
Electric - Commercial VOLLs = Industrial VOLLs	[c]	$769	$515
Gas	[d]	$640	$640
High Range	[e]	$18,235	$12,429
Mid Range	[f]	$3,511	$2,564
Low Range	[g]	$1,410	$1,156
High Range - w/ Combined E&G Effect	[h]	$17,872	$12,073
Mid Range - w/ Combined E&G Effect	[i]	$3,148	$2,208
Low Range - w/ Combined E&G Effect	[j]	$1,094	$944

Sources and Notes:
[1a]: Commercial VOLL equal to $315.
[1b]: Commercial VOLL equal to $49.
[1c]: Commercial VOLL equal to $11.
[1d]: *The Brattle Group* © 2013[2a-c]: [1] x (1 - 33%)
[e]: [a] + [d]
[f]: [b] + [d]
[g]: [c] + [d]
[h] through [j]: *The Brattle Group* ©2013

Combining the value to customers of mitigating both electric and gas outages, and taking outage coincidence and the effects on value of customers who take combined electric and gas services into account, the likely value to customers of PSE&G's ES program investments is ranges from approximately $944 million to $12.1 billion, centered around our point estimate of roughly $2.2 billion.

Varying the VOLLs per unserved kWhs for commercial customers also has an impact on the break-even outage duration of required for values to customers to equal the PVs of PSE&G's ES program investments. **Table V-2** shows that under the high VOLL per unserved kWh case, only 0.5 outage days are needed before electric customers realize value equal to the PV of the Electric ES sub-program investment costs. This break-even increases to approximately 11.5 days when the VOLL per unserved kWh for commercial electric customers is lowered to equal VOLL levels applied to industrial customers. This range of break-even outage durations is centered around our estimate of 3.08 days for electric customers. We did not vary the VOLL-equivalent for PSE&G's gas customers. We estimated the break-even duration of outage for PSE&G's Gas ES sub-programs to be roughly 7.08 days overall.

Table V-2
Summary of Break-Even Analysis
(Outage Days)

		Coincidence Factor	
		Aggregate Non-Coincident	**33%**
		[1]	[2]
Electric - As Published Berkeley VOLLs	[a]	0.34	0.50
Electric - Median Comm VOLLs	[b]	2.06	3.08
Electric - Comm VOLLs = Industrial VOLLs	[c]	7.70	11.50
Gas	[d]	7.08	7.08

Sources and Notes:
[a] through [c]: $1,975 x 1,000,000 / (Table V-1 / 3).
[d]: $907 x 1,000,000 / (Table V-1 [d] / 5).

The assumptions included in our analysis can also be modified in order to produce very low levels of benefits. For example, very high coincidence factors applied to PSE&G's Electric ES sub-programs, combined with low VOLLs per unserved kWh for commercial electric customers and reduced daily values for avoided loss of gas service will, by definition, produce low levels of benefits.

We consider our estimates – our value estimate of $2.2 billion and our break-even outage durations of 3.08 days to cover Electric ES investments and 7.08 days to cover Gas ES – to be conservative, with the sub-programs that produce high value and low break-even outage durations making up for necessary (but higher break-even) last mile infrastructure investments. These overall levels of value and break-even outage durations suggest that PSE&G's Electric and Gas ES programs have economic merit on an overall basis. Our analysis suggests that the duration of electric outage resulting from a single storm the size of Superstorm Sandy or from several less severe storms (such as Hurricane Irene) over the life of the program assets would be sufficient for electric customers to "break-even" or realize value sufficient to cover the cost of PSE&G's Electric ES investments. These benefits would flow to most or all of PSE&G's electric customers. The direct benefits flowing from major weather events – specifically, between one and two multi-day gas outage events – would also cover the investment costs associated with PSE&G's Gas ES sub-programs. Other benefits, notably those associated with the UPCI sub-program and which we did not quantify, are also likely to be significant.

APPENDIX A

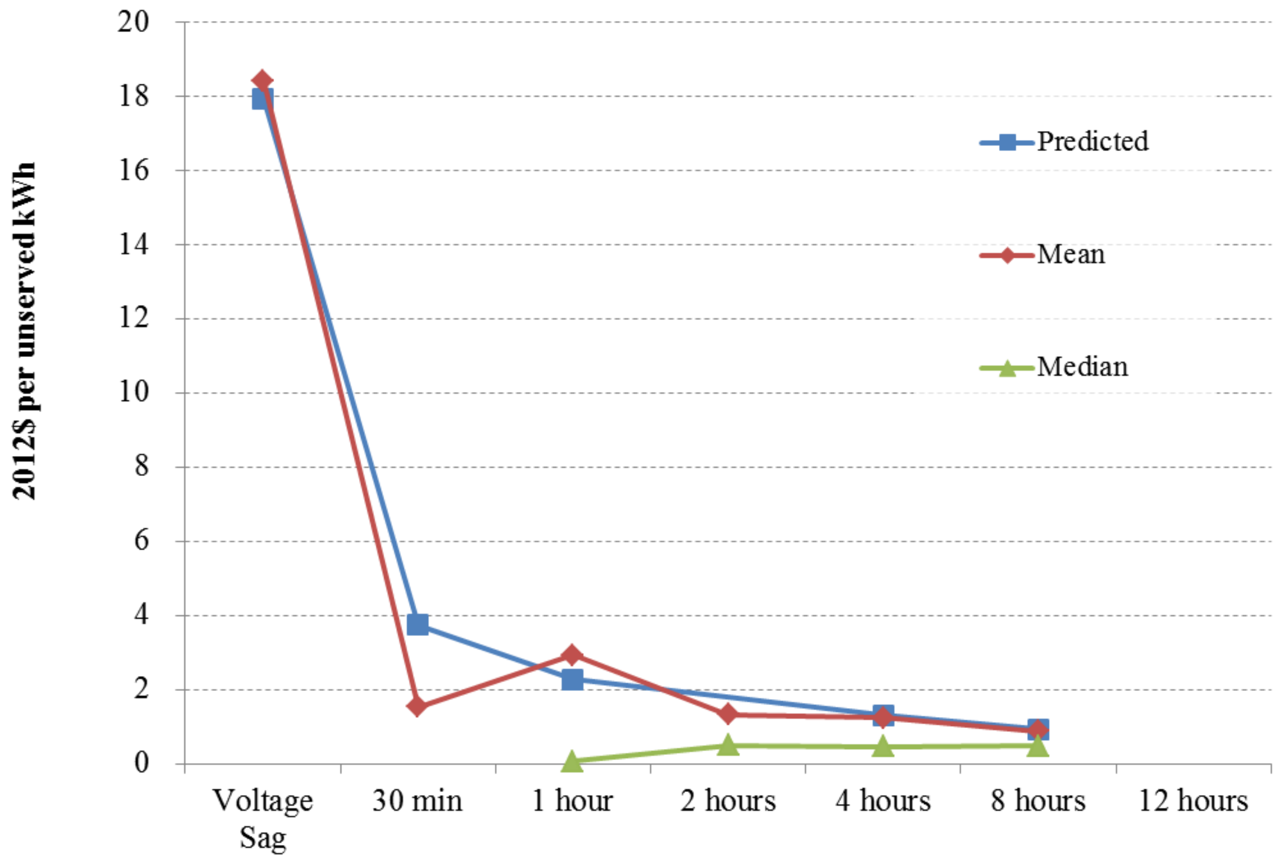
Appendix A-1
Summary of Total Energy Strong Investment Costs
(2012 $)

			Proposed Investment (2012$ millions)					
Investment Area	Program	Investment Initiative / Action	Months 1 - 60	Months 61 - 120	Total	Present Value of Months 1 - 60	Present Value of Months 61 - 120	Total Present Value
Initiative Target: Individual Circuits / Customers								
Asset Hardening	Enhance OP Construction Standards	Convert 4kV distribution plant to 13kV standards	$65	$0	$65	$53	$0	$53
Asset Hardening	Enhance OP Construction Standards	Convert 26kV distribution plant to 69kV standards (while still operating at 26kV)	$60	$0	$60	$49	$0	$49
Asset Hardening	Enhance OP Construction Standards	Add spacer cable to eliminate open wire to targeted areas	$10	$0	$10	$8	$0	$8
Asset Hardening	Strengthening Pole Infrastructure	Increased pole diameters, reduced span lengths and enhanced storm guying	$102	$0	$102	$82	$0	$82
Asset Hardening	Strengthening Pole Infrastructure	Install non-wood poles	$3	$0	$3	$2	$0	$2
Asset Hardening	Rebuild/Relocate Backyard Poles	Rebuild backyard poles (including tree trimming)	$100	$0	$100	$81	$0	$81
Asset Hardening	Undergrounding	Convert targeted OH areas to UG	$60	$0	$60	$49	$0	$49
Asset Hardening	Undergrounding	Replace PM transformers with submersibles (in target areas)	$8	$0	$8	$6	$0	$6
Asset Hardening	Undergrounding	Replace ATS switches/transformers with submersible switches	$8	$0	$8	$6	$0	$6
System Resiliency	Advanced Technologies	Create multiple system sections using smart switches, smart fuses, and adding redundancy within PSE&G loop scheme	$200	$0	$200	$162	$0	$162
Supplemental	Emergency Backup Generator and Quick Connects	Deploy emergency generators (municipal determined priorities) and quick connects	$2	$0	$2	$2	$0	$2
Supplemental	Storm Plan - Municipal Pilot Program	Veg managament, mobile field apps and CHP for critical municipal facilities	$0	$0	$0	$0	$0	$0
Total Investment: Individual Circuits / Customers			$618	$0	$618	$500	$0	$500
Initiative Target: Substations Feeder Groups								
Asset Hardening	Station Flood Mitigation	Raising/rebuilding infrastructure and installing flood walls.	$819	$859	$1,678	$662	$483	$1,145
System Resiliency	Advanced Technologies	System Visibility- 26kV, 13kV, and 4kV Microprocessor Relays and SCADA field equipment (RTUs) to enable remote monitoring and operations	$120	$130	$250	$97	$73	$170
Total Investment: Substations / Feeder Groups			$939	$989	$1,928	$759	$556	$1,315
Initiative Target: Operating Centers								
Asset Hardening	Relocate Critical PSE&G Operating Center	Relocate ESOC, GSOC, DERC and SR	$15	$0	$15	$13	$0	$13
Initiative Target: System Wide								
System Resiliency	Advanced Technologies	System Visibility - SCADA monitors and servers, dispatch consoles, communications switches	$24	$26	$50	$19	$15	$34
System Resiliency	Advanced Technologies	Communications Network - fiber optic transmission backbone and 91 of PSE&G's 125 distribution substations	$35	$38	$73	$28	$21	$50
System Resiliency	Advanced Technologies	Communications Network - satellite communication program (pilot)	$3	$0	$3	$2	$0	$2
System Resiliency	Advanced Technologies	Advanced Distribution Management System (ADMS) to integrate SCADA, DMS, OMS and GIS systems	$9	$6	$15	$7	$3	$11
System Resiliency	Advanced Technologies	Enhance storm management systems	$50	$0	$50	$42	$0	$42
System Resiliency	Advanced Technologies	Communication channels expansion to improve customer access to information (outage maps, mobile apps, preference management, SMS, mobile web)	$10	$0	$10	$9	$0	$9
Total Investment: System Wide			$131	$70	$201	$108	$39	$147
Total Investment: Electric Energy Strong			**$1,703**	**$1,059**	**$2,762**	**$1,380**	**$595**	**$1,975**
Initiative Target: Gas Energy Strong Invesments								
Asset Hardening	M&R Stations	Metering & Regulating Station Flood and Storm Surge Mitigation	$76	$64	$140	$61	$39	$100
Asset Hardening	UPCI	Utilization Pressure Cast Iron (UPCI)	$830	$210	$1,040	$671	$136	$807
Total Investment: Gas Energy Strong			**$906**	**$274**	**$1,180**	**$732**	**$174**	**$907**
Total Energy Strong Investment			**$2,609**	**$1,333**	**$3,942**	**$2,113**	**$770**	**$2,882**

Sources and Notes: PSE&G Energy Strong Filings, BPU Docket Nos. EO13030155 and GO13020156.
Present value derived by applying an even distribution of Phase I and Phase II spending across Phase I and Phase II years, respectively, and application of a discount rate of 7.01%, as used by PSE&G in its Energy Strong filings with the BPU.

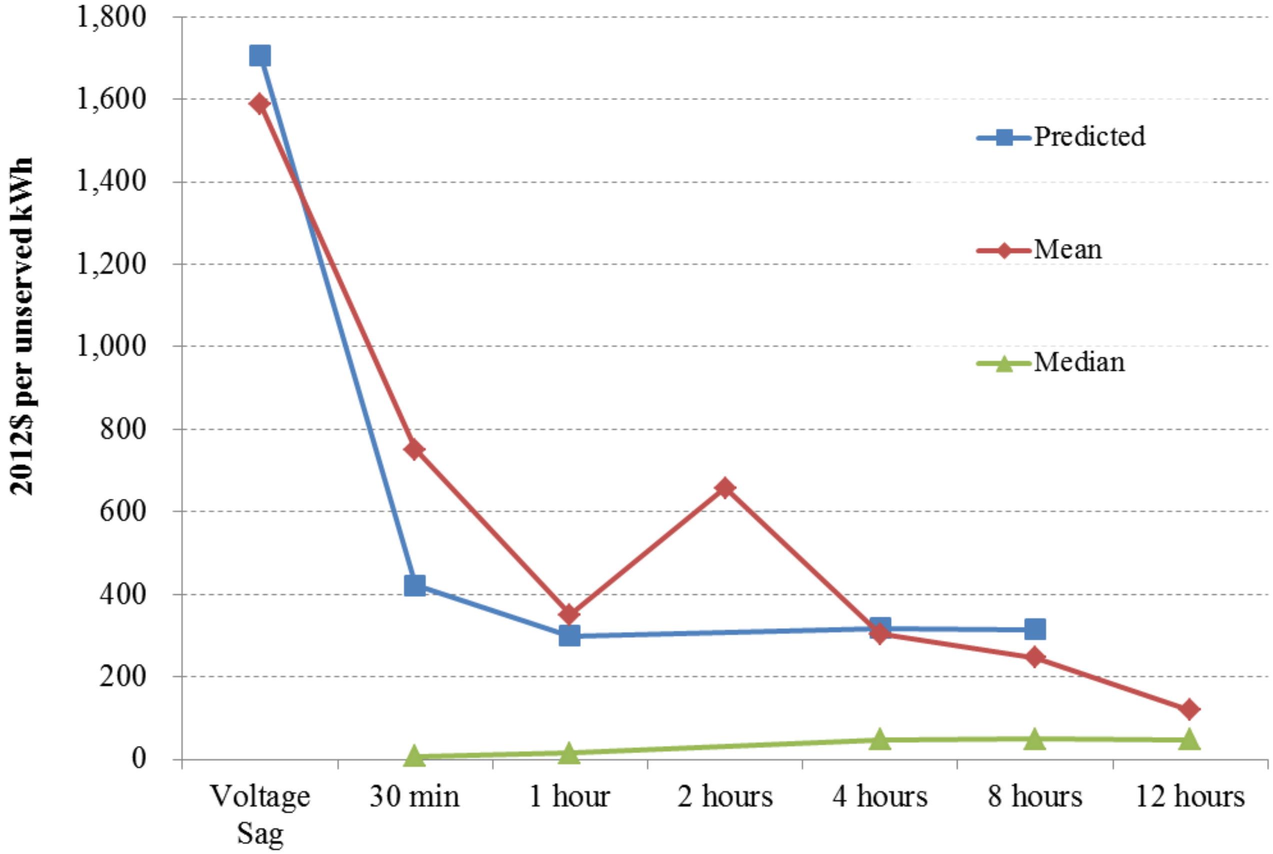
APPENDIX B

Appendix B-1
Value of Lost Load
Predicted, Mean and Median Values –Per Unserved kWh
Residential Customers



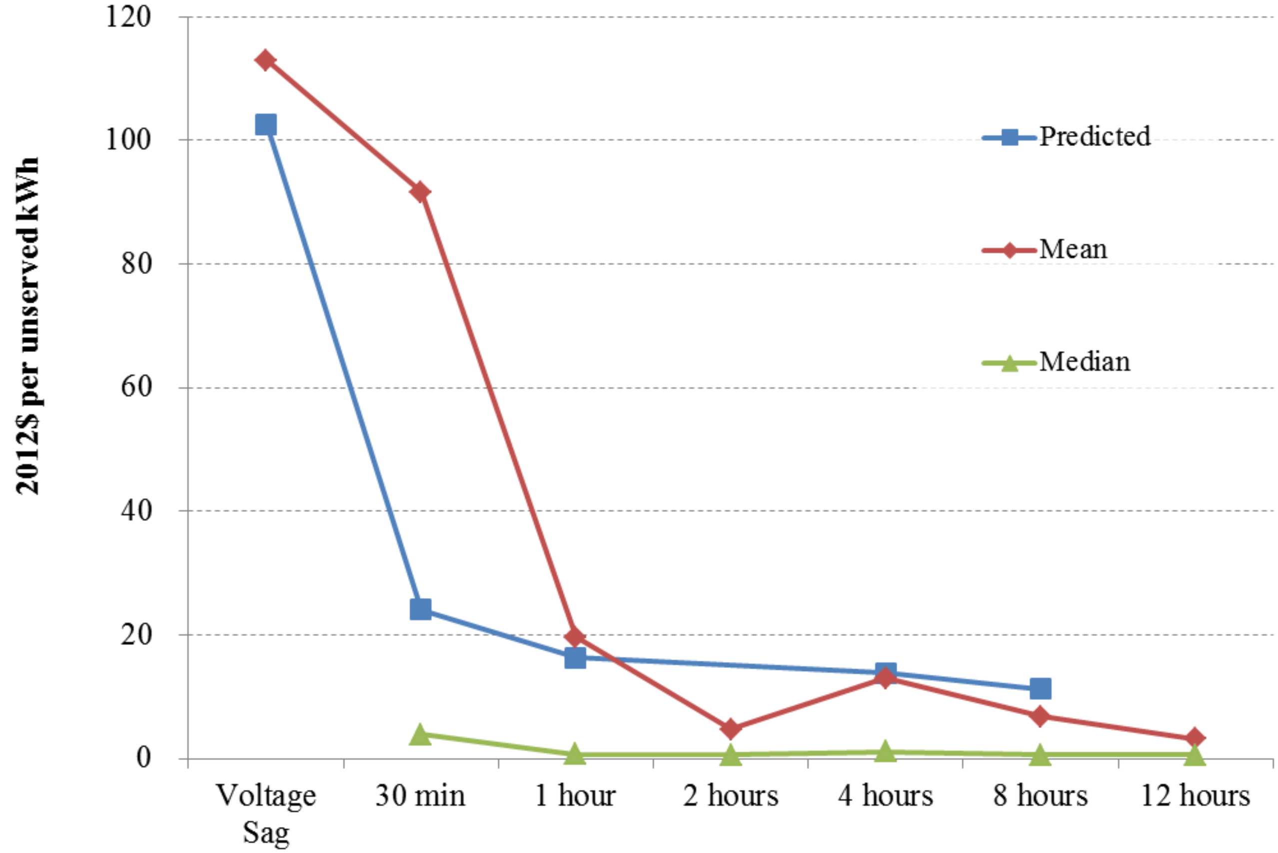
Source: Sullivan, M., Mercurio, M., and Schellenberg, J. (2009) *Estimated Value of Service Reliability for Electric Utility Customers in the United States.* Lawrence Berkley National Laboratory.

Appendix B-2
Value of Lost Load
Predicted, Mean and Median Values –Per Unserved kWh
Small Commercial and Industrial Customers



Source: Sullivan, M., Mercurio, M., and Schellenberg, J. (2009) *Estimated Value of Service Reliability for Electric Utility Customers in the United States.* Lawrence Berkley National Laboratory.

Appendix B-3
Value of Lost Load
Predicted, Mean and Median Values –Per Unserved kWh
Medium / Large Commercial and Industrial Customers



Source: Sullivan, M., Mercurio, M., and Schellenberg, J. (2009) *Estimated Value of Service Reliability for Electric Utility Customers in the United States.* Lawrence Berkley National Laboratory.