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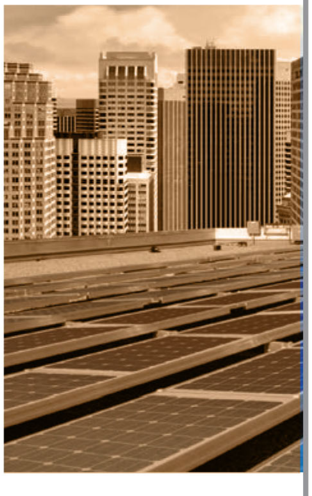

Investing in Grid Modernization:

The Business Case for Empowering Consumers, Communities and Utilities

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This paper can be accessed online at: www.PerfectPowerInstitute.org.

Robert W. Galvin founded the Galvin Electricity Initiative to transform our electric power system into one that is reliable, efficient, secure and clean, and meets the needs of 21st century consumers. Since 2005, the Initiative has been sparking a migration toward a consumer-driven electric power system that is based on quality leadership. The newly formed Perfect Power Institute represents the next phase of the Initiative's efforts and will catalyze power system transformation by sharing best practices, educating industry stakeholders and setting the standard for system performance via the Perfect Power Seal of Approval™ program. For more information visit **www.perfectpowerinstitute.org**, "like" **Facebook.com/galvinpower** and "follow" **Twitter.com/perfectpower**. For Galvin Electricity Initiative resources, visit **http://www.galvinpower.org/resources/library/introduction**.

Executive Summary

Consumers could realize benefits that exceed the investment costs for modernization by a factor of three or more if they, along with local governments and innovators, are engaged as partners in grid modernizations. The Perfect Power Institute™ estimates the potential benefits of investments to be about $1,200 per year for a typical household with an estimated cost of about $400 per year, per household. The estimated benefits would be even higher if the impact on public health, safety and security could be precisely quantified and included.

Smart Grid Costs and Benefits Summary

SECTION	COST CATEGORY	COST PER YEAR PER HOUSEHOLD
5.0	Total Estimated Cost (over a 15-year period)	**~$400**
	▪ Clean power supply investment	$80
	▪ Transmission and distribution investment	$150
	▪ End-use investment, including local power	$165
SECTION	**BENEFITS CATEGORY**	**VALUE PER YEAR PER HOUSEHOLD**
6.0	Total Estimated Savings (excluding security and safety)	**~$1,200**
	▪ Direct bill savings (including smaller rate increases)	$585
	▪ Indirect benefits (e.g., reduced economic losses and deaths)	$400
	▪ Future revenue (e.g., from providing grid services)	$250

Information on calculations for this table are included in Sections 5 and 6 of this research paper.

The investment costs are estimated across three main grid categories — power supply, power delivery and end-use consumption — with the greatest investment made at the consumption level. The benefits for a household include: direct cost savings, such as avoided rate increases, which will appear on the customer bill; indirect savings, such as reduced economic losses due to power interruptions, which are not reflected on the customer bill; and future revenue potential for providing electricity and ancillary services to the grid. Consumer benefits will increase over time but the maximum benefits estimated as part of this paper could take five or more years to be realized as the savings shown will be utilized to offset investment in system improvements. This means that consumers may not see all, or most, of these savings until the investments are paid off.

To realize the full potential of these investments and benefits, market reforms must be made that empower consumers enabling them to generate greater savings and earn revenue for grid services. A new electricity market that values customer participation will attract the interest and investment of technology innovators. Local governments ought to become key partners and investors in local electricity system improvements, enabling them to specify local needs and coordinate with local infrastructure projects and programs to lower grid modernization costs. Focused on local systems, these investments can produce greater impacts.

Finally, grid modernization depends on a new utility regulatory compact that rewards system operators for tracking and eliminating system waste, such as the economic impact of outages and operational inefficiencies. Indirect costs are substantial and should be quantified and tracked for use in system improvement. Investments in the elimination of system waste can pay for themselves.

Contents

Figures

Tables

1 Introduction

The U.S. electricity system is wasting significant amounts of both energy and capital. Not only does this inefficiency squander precious resources, but it also forces consumers to incur higher than necessary monthly electricity costs and indirect costs. An updated, modern electricity grid could reduce or even eliminate this waste, reduce costs associated with an inefficient system and improve societal and economic conditions.

The projected benefits include:

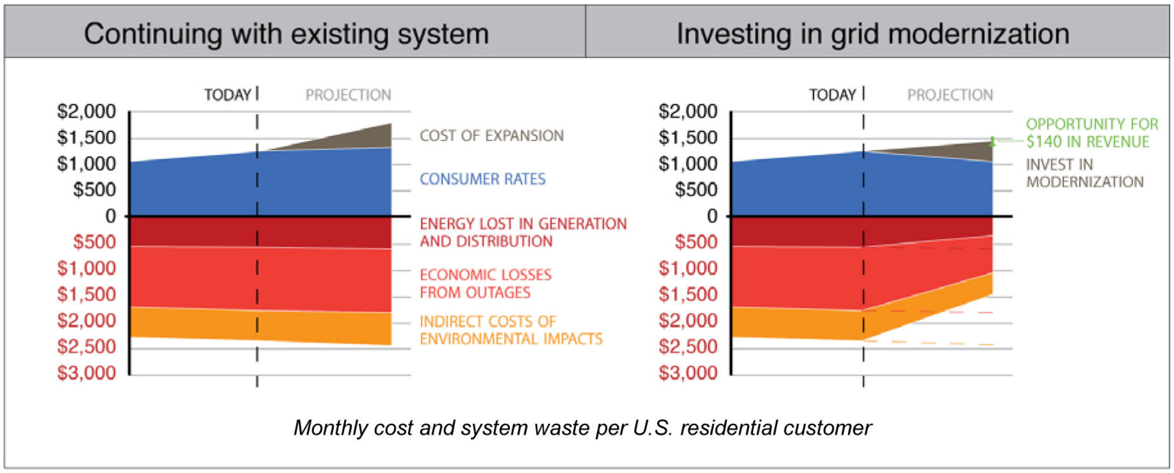
- Direct bill savings;
- Indirect savings (e.g., economic losses from power interruptions);
- Opportunity for consumers to generate revenue;
- Job creation and economic competitiveness; and
- Reduced environmental impacts.

This research paper explores the costs and benefits associated with grid modernization. It provides estimates of the investments and potential benefits based on the opportunities for eliminating system waste; lowering electricity costs; reducing environmental impacts; and improving power efficiency, safety, reliability and quality.

Updating our nation's aging electricity grid — like many infrastructure projects — is widely regarded as a national priority. Consumers acknowledge that the grid is not perfect and that they would like to see it improved, but have by and large learned to live with it as is. System operators speak of cost savings associated with grid modernization, but ratepayers are cautious when it comes to increased rates and wonder why rates must go up if this new system will save so much money.

The question is not whether we should pay for improvements, because we are already paying. The question is, "What would we rather pay for: a steady stream of waste, or an investment to stop it?"

If the system continues to operate inefficiently, significant increases in peak load will require system expansion to meet this new capacity, leading to rate increases while no investments are made to reduce these costs by eliminating system waste. Grid modernization, on the other hand, can *reduce* these costs by eliminating trillions of dollars of waste. Investment in a more efficient system would eliminate the need for these expansion costs while increasing the effectiveness and efficiency of the system, leading to reduced rates in the future. With investment in grid modernization, system waste can be reduced by 31 percent while enabling households to realize direct bill savings of 18 percent and earn revenue, about $140 a month, for supplying electricity services.



Monthly cost and system waste per U.S. residential customer

Table 1: Maintaining Electricity System Waste vs. Investing in Grid Modernization

See Tables 2, 3 and 6 for information on how these numbers were derived.

The paper begins with an introduction to the need for grid modernization and the work the Perfect Power Institute has done to understand the costs and benefits. Section 2 goes into further detail of what grid modernization is and characteristics of successful implementation. Section 3 discusses the existing system and associated waste, how these sunk costs are imbedded in the customer bill and finally how Naperville was able to reverse this dynamic and implement successful grid modernization. Section 4 introduces key policy and process changes that are necessary for customers to realize the full benefits of grid modernization and provides specific performance outcomes that are required to realize the benefits projections. Section 5 estimates the investment costs necessary to modernize the grid and Section 6 estimates the potential benefits. The report concludes with Section 7 that provides the impetus for change and improvement of the electricity grid.

1.1 PROJECT BACKGROUND

The Perfect Power Institute™, working with industry stakeholders, has researched smart grid performance measures and outcomes in the process of creating the Perfect Power Seal of Approval™. This includes exploring prototypes that exceed the outcomes presented in this paper and researching policy best practices that maximize customer benefits.

The Institute's work and primary references include:

- The **Illinois Electricity System Guiding Principles and Policy Framework** report, which records five years of collaboration, research and outreach into consumer needs and policy reform best practices. This includes the results of a Constitutional Convention with a broad set of stakeholders to identify policy reforms that would lead to a more consumer responsive electricity system.
- The **Perfect Power Seal of Approval** is the nation's first comprehensive, consumer-centric, data-driven system for evaluating power system performance. It has been developed by the independent nonprofit Galvin Electricity Initiative along with strategic partner Underwriters Laboratories and a team of industry experts.

- **Perfect Power at IIT** is a demonstration that cost-effective power can be delivered to the consumer precisely as the consumer requires it, without failure and without increasing costs. The Illinois Institute of Technology (IIT) collaborated with the Galvin Electricity Initiative, S&C Electric Company, Endurant Energy and Commonwealth Edison to design a Perfect Power system for the IIT campus in Chicago.
- The **Naperville Smart Grid Initiative** has made efforts to update their power grid to be more reliable, cost-competitive and efficient, placing themselves as one of FORTUNE Small Business' Best Places to Live and Launch in 2008.
- **Estimating the Costs and Benefits of the Smart Grid** — an EPRI report from 2011 with preliminary estimates of the investment requirements and resultant benefits of a fully functioning Smart Grid — was utilized to provide input regarding grid modernization scope and costs.
- **Energy Information Association Annual Energy Outlook 2011** reports current and projected energy demand, use and generation capacity, and was used to provide input regarding consumption and capacity projections.
- **Maximizing Consumer Value Through Dynamic Pricing: A Suggested Approach for Regulatory Reform** reveals the importance of market-based pricing in maximizing consumer benefits associated with advanced metering.

The Initiative has used this information to construct the cost benefit analysis in this research paper. To learn more about the work of the Initiative and its partners visit www.PerfectPowerInstitute.org.

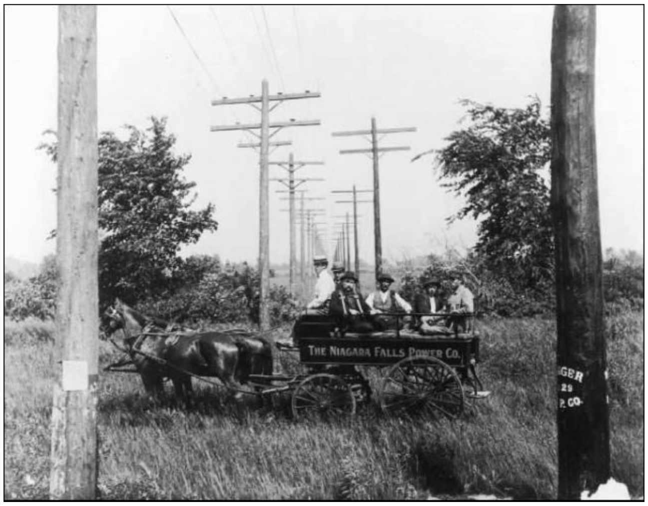
2 What Is Grid Modernization?

2.1 GOALS OF GRID MODERNIZATION

The term “grid modernization” can mean many things, which is part of the problem some have in grasping the idea. In whatever form grid modernization changes may take, they are all trying to solve the five biggest problems facing our aging grid by:

1) Eliminating the significant amount of waste and lowering costs;
2) Improving safety, reliability and power quality;
3) Improving energy efficiency;
4) Reducing environmental impacts; and
5) Improving aesthetics.

This requires a comprehensive transformation of the electricity system rules and design[1] that have remained essentially the same for the past century. In the photo on the right, you’ll notice the basic grid design from 1895 looks much as it does today, while primary modes of transportation have changed a great deal. The U.S. Department of Energy has said that our nation's competitiveness depends upon a modernization of our electricity system.



Line crew of Niagara Falls Power Co. in 1895.

Image 79-2142, Electricity & Modern Physics Collection, National Museum of American History, Smithsonian Institution, copyright, Smithsonian Institution

Strategies to accomplish these five goals can range from relatively straightforward initiatives, like undergrounding distribution wires, to often-discussed (and just as often misunderstood) investments in making the grid smarter by expanding the use of communications and information technologies to boost flexibility and functionality. Because it is so complex and has wide implications, this paper delves a little deeper into the nature of the smart grid.

2.2 INVESTMENT CATEGORIES

Much like grid modernization, the phrase “smart grid” is a generic term that incorporates many different technologies and applications. It can be divided into three broad investment or cost categories:

1) **Power supply or procurement improvements**, which focus on generation efficiency improvement and eliminating environmental impacts.
2) **Power delivery improvements**, which measurably improve safety, reliability, power quality and efficiency of delivery. In addition, these improvements enable two-way power

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[1] Kelly, J., Rouse, G., & Nechas, R. (2010, July 15). Illinois Electricity System: Guiding Principles and Policy Framework. Retrieved from http://www.galvinpower.org/resources/library/reports-white-papers

flow, interconnect, pricing markets and direct access to near real-time usage data. To learn more about best practices for improving grid reliability, review the Galvin Electricity Initiative white paper titled “Electricity Reliability and Policy Solutions.”[2]

3) **End-use improvements**, which result in conservation, cost reduction and the adoption of cleaner generation sources. This includes encouraging and enabling consumer investment in technologies that allow them to realize improvement results through choice, local generation and automation. With advanced metering devices, for example, customers can receive feedback from the grid that notifies them when electricity prices are at their highest and lowest. In addition, smart meters and dynamic pricing at the home can encourage customers to conserve and provide grid ancillary services.

2.3 SUCCESS CHARACTERISTICS

The Galvin Electricity Initiative has developed a comprehensive set of smart grid performance metrics[3] and completed several prototypes of advanced smart grids.[4] The Initiative has also completed Perfect Power prototypes and case studies that provide insight into effective and innovative smart grid design approaches.[5] These efforts identified several key characteristics of effective smart grid programs and projects. Most important, early prototypes reveal that investment in the local distribution system provides the greatest impact on performance.

Below are some of the key characteristics of these programs and projects:

- **Achieving specific, measurable goals**[6] — Effective smart grid investment projects begin with measurable performance goals or outcomes, such as average interruption duration and frequency reduction.
- **Self-healing infrastructure** — The grid rapidly detects, analyzes, responds to and resolves problems, faults or attacks. This can be accomplished through integration of redundancy, substation automation and smart sectionalizing switches.
- **Empowering and engaging the consumer** — The grid should have the ability to accommodate dynamic pricing, ancillary services from consumers, and net metering of local clean generation.
- **Defending against attack** — The grid should be resilient to and be able to mitigate physical and cyber-attacks. This includes effective cyber security and protecting exposed components as well as moving critical system components underground.

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[2] Rouse, G., & Kelly, J. (2011, February). *Electric Reliability: Problems, Progress, and Policy Solutions.* Retrieved from http://www.galvinpower.org/resources/library/reports-white-papers

[3] Galvin Electricity Initiative. (2011). *Perfect Power Seal of Approval.* Retrieved from http://www.galvinpower.org/sealofapproval

[4] Galvin Electricity Initiative. (2007). *Perfect Power prototype design reports for the Illinois Institute of Technology and the Mesa del Sol development.* Retrieved from http://galvinpower.org/projects/perfect-power-illinois-institute-technology

[5] Galvin Electricity Initiative. (2007). *Perfect Power prototype design reports for the Illinois Institute of Technology and the Mesa del Sol development* and Galvin Electricity Initiative. (2010, April). *Naperville Case Study.* Retrieved from http://www.galvinpower.org/galvin-conducts-naperville-smart-grid-initiative-case-study

[6] Galvin Electricity Initiative. (2011). *Perfect Power Seal of Approval.* Retrieved from http://www.galvinpower.org/sealofapproval

- **Providing power quality needed by 21st century users** — The grid should provide power reliability and quality consistent with consumer and industry needs.
- **Accommodating a wide variety of supply and demand** — The grid should accommodate a variety of local generation resources (storage, solar and gas-fired generation) and demand-side resources (demand response, load management and end-use efficiency programs).
- **Enabling mature electricity markets** — The grid should allow for and be supported where practical by competitive markets that engage consumers in ancillary services.

The realization of grid modernization would require a fundamental change from the electric power industry's traditional focus on supply-side infrastructure that ends at the meter to one that includes more fully the numerous individualized service and supply opportunities on the demand side. Such a comprehensive change in the electric power industry will require a great deal of investment. The cost of modernizing the grid is often cited as a reason for not undertaking the project, but this reasoning does not factor in the value of the potential benefits or the elimination of inefficiency and waste that is part of the current system.

3 Electricity System Waste

The U.S. electricity system is wasting significant amounts of energy and capital while producing unacceptable amounts of harmful emissions. Waste in the electric sector is costing America roughly a half trillion dollars each year in five areas (see Table 2 on page 11):

1) **Building Conservation —** Today's building materials are relatively inefficient, resulting in high energy loss. Lawrence Berkeley National Laboratory (LBNL) estimated that building owners could save up to 30 percent through conservation.[7] Assuming that 50 percent improvement in residential and commercial building efficiency is the theoretical limit, the total waste is <u>$150 billion annually</u>.[8]

2) **Capacity Expansion —** Even though only about 50 percent of the current ~1,000 GW of generation and delivery system is utilized, additional capacity is projected to keep up with growth in peak demand — demand that continues to grow due to the lack of consumer response to daily swings in power demand. As a result, about 100 GW of new generation and delivery is called for and will be required to meet increasing peak demand. This is about 600 GW in unutilized capacity, representing waste of about <u>$60 billion,</u> assuming generation and delivery costs of approximately $3,700 per kW.

3) **Generation and Distribution Energy Efficiency —** Because fossil fuel has been relatively inexpensive to process, large power plants are not built to operate as efficiently as is technically feasible, and they waste about two-thirds of the fuel they consume.[9] The power plants and lines that generate and carry power to our cities and towns have to send a large quantity of electricity a long way, losing thermal energy to the surrounding air and wasting up to another 7 percent of the electricity delivered.[10] This equates to about 25 quadrillion BTU or <u>$70 billion annually at $3/mmBTU</u> in wasted fuel.

4) **Power Reliability and Quality —** Our power lines are out in the open where they fall prey to weather, animals and accidents. When the power lines are damaged, utilities, consumers and businesses pay for the resulting repairs and economic losses. Electricity interruptions also cause injuries and deaths, resulting from lost power to life-safety equipment, heating and cooling, as well as causing fires and electrocutions. Consumer impacts include flooded basements due to inoperable sump pumps, spoiled food and increased cost of goods due to business downtime and lost productivity. The total estimated annual cost is about <u>$150 billion annually</u>.[11]

5) **Environmental Impacts —** The electric power sector is a major contributor to carbon, sulfur, mercury and other hazardous emissions. The full human health and environmental

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[7] Brown, R., Borgeson, S., Koomey, J., & Biermayer, P. (2008). *U.S. Building-Sector Energy Efficiency Potential, LBNL-1096E.* Berkeley: Ernest Orlando Lawrence Berkeley National Laboratory.

[8] From the *Annual Energy Outlook 2010*, total electricity usage for residential and commercial buildings totaled 2,700 billion kWh, assuming 40 percent of the electricity is wasted.

[9] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Tables A1 – A20.

[10] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* p.10.

[11] LaCammare, K. H., & Eto, J. H. (2004). *Understanding the Cost of Power Interruptions to U.S. Electricity Consumers, LBNL 55718.* Ernest Orlando Lawrence Berkeley National Laboratory, Energy Analysis. Berkeley: University of California Berkeley.

consequences of this is not known, but it is certainly a strain on the U.S. economy and health care system. In terms of just carbon, sulfur and nitrogen oxide emissions, the costs are estimated at about $70 billion annually (see Section 6.3.2).

Table 2: Electricity System Waste Summary (Direct and Indirect)

WASTE CATEGORY	IMPACT	WASTE $, BILLIONS	RECOVERABLE $, BILLIONS (SECTION 6)	METRIC EXAMPLES[12]
Building conservation	Potential direct consumer savings	~150	~90	Energy Star Rating
Capacity expansion	Wasted capital that can be avoided	~60	~24	System capacity factor* System demand factor**
Generation and distribution energy efficiency	Potential direct consumer savings	~70	~36	Source Energy Intensity***
Power reliability and quality	Potential indirect consumer savings	~150	~75	Interruption duration and frequency index and power quality measures
Environmental impacts	Potential indirect consumer savings	~70	~20	Carbon, sulfur, nitrogen oxide intensities
Total Cost		**~500**	**~245**	To put this in perspective, we divided the total waste by the total U.S. consumption, which equates to 13 cents/kWh[13]

*System capacity factor = the total system-delivered MWh divided by the system peak capacity in MWh times 8,760 hours.

**System demand factor = the total system-delivered MWh divided by the peak summer demand corrected for heating degree day (HDD) times 8,760 hours.

*** Energy Star created the source energy intensity as a means to measure the overall efficiency of delivered electricity, which equals total fossil fuel consumed in mmBTU divided by the delivered MWh of electricity.

Source: Galvin Electricity Initiative (2011). *Perfect Power Seal of Approval* and U.S. Department of Energy *Annual Energy Outlook 2010. Note: This table is a summary of estimated total electricity system waste for the selected waste categories. The savings discussed herein reflect recovery of a portion of these savings as a result of electricity system investments and rule changes that enable or produce specific system improvements. The basis for these estimates is provided in Section 6.0. The building efficiency savings do not include structural efficiency savings, only energy savings from automation and behavioral changes due to new knowledge.*

3.1 WHO PAYS FOR SYSTEM WASTE?

The most common argument against grid modernization is that upgrading the grid would be too expensive. While consumers acknowledge the need for improvement, most will not embrace upgrades to a system they can live with the way it is. They don’t realize that they are already paying for what is wrong with the system, and that improvement can *reduce* these costs.

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[12] Galvin Electricity Initiative. (2011). *Perfect Power Seal of Approval.* Retrieved from http://www.galvinpower.org/sealofapproval

[13] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* estimates total annual electricity usage at 3,730 billion kWh and residential/commercial annual usage at 2,700 billion kWh.

Grid modernization, done right, can eliminate waste, increase the efficiency of operations and shift spending to more impactful improvements. Of course, these improvements do cost money. Think of it as a one-time payment to the plumber to fix the leaky faucet that is driving up your water bill. If you don't pay to have it fixed now, you will be paying in drips until you do.

Consumers are currently paying utilities to manage system operation and performance through distribution charges. These distribution charges are reviewed every few years with regulators to ensure that they are accurate. In order to guarantee the utility will not go out of business and leave consumers without power, they add a modest guaranteed profit and let the utility charge that much for electricity for the next rate period.

The current regulatory environment does not account for the indirect or direct costs of outages, thereby limiting investment that could eliminate waste associated with power interruptions. As a result, the waste or consumer costs caused by interruptions cannot be used to justify investment. This includes: 1) injuries and deaths, 2) recovery and repair costs, separate from maintenance or operations costs, and 3) economic losses to families and businesses when the power fails.

To further exacerbate the situation, a significant portion of the existing customer's delivery charge is invested in system expansion and higher voltage system improvements, even though LBNL reported that the majority of power interruptions are not caused by the transmission or area-wide high-voltage distribution system but are instead due to events that affect the local low-voltage distribution system.[14] Essentially investments are being diverted from improvements that would reduce interruptions to support new customers. For example, PEPCo in response to widespread power interruptions, announced a Comprehensive Reliability Enhancement Plan[15] that allocated 60 percent of the targeted $320 million in improvement spending to system expansion.

As a result, consumers can benefit from a new regulatory compact that:

- Enables consumers and utilities to track waste and share in savings from investment that eliminates both direct and indirect waste.
- Assigns the cost of system expansion to new load, thereby allowing utilities to focus limited investment spending on the existing grid.

3.2 NAPERVILLE — ELIMINATING WASTE AND TARGETING INVESTMENT

Some industry stakeholders have argued that higher rates are required to improve the reliability of electricity service. In the case of Naperville, Ill., dramatic improvements in system reliability were achieved without raising rates (See Appendix A). Naperville turned this dynamic by: 1) shifting spending to the local grid, 2) making new development pay for system expansion, 3) moving the system underground to eliminate the continuous waste associated with storm recovery, and 4) creating isolation capability to limit storm impacts and restoration costs. The

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[14] Illinois Commerce Commission. (2010). *Electric Reliability Reports*. Retrieved from http://www.icc.illinois.gov/electricity/electricreliability.aspx.

[15] Pepco. (2010). *Pepco Unveils Reliability Enhancement Plan for the District of Columbia.* Retrieved from http://www.pepco.com/welcome/news/releases/archives/2010/article.aspx?cid=1552

result was a dramatic improvement in reliability that also reduced system waste along with operation and maintenance costs that were ultimately used to pay for investments.

This was accomplished by moving the system underground, building in redundant supply to buildings, automating switches to re-route power in the case of a failure and communications with all devices. A benefit of smart power technology is having the ability to acquire and access data detailing how the distribution system is functioning. In order for Naperville to capitalize on this advantage, they built a centralized location for all of the incoming data to be directed, called the Electric Service Center. From the Center's control room, also known as the "smart grid brain," a real-time data acquisition system called System Control & Data Acquisition (SCADA) gathered and processed critical data.

SCADA is crucial for real-time operation and requires reliable, two-way communication with the substations. Monitoring SCADA from the Electric Service Center's controls allowed the Naperville team to forecast and plan their system better, fix problems using controls from the Center's control room, as well as dispatch people to address problems quicker. Thus, SCADA became the backbone of Naperville's power system, and the first step toward improving their grid.

In addition, Naperville recognized that collected distribution monies are sometimes siphoned away from local reliability improvements for system expansion and new development while system inefficiency and recurring repairs continue. They took a bold step, charging new customers a temporary special rate, or rider, that covered the cost of system expansion to serve new customers. This allowed Naperville to apply rates collected from existing customers to the smart grid project.

4 Investment and Benefit Prerequisites

Research into grid modernization benefits revealed the need to empower and value consumers in order to produce the benefits estimated herein. These benefits depend, naturally, upon grid modernization investments producing specific measurable improvements. As such, the benefits outlined in this research paper depend on market reforms, changes in the system processes and achieving specific, measurable outcomes.

The benefit estimates are based on grid investments producing significant, measurable results:

- 50 percent or more improvement to interruption duration/frequency and power quality measures;
- 15 percent reduction in peak demand-reducing costs associated with system expansion;
- 50 percent reductions in inefficiency, economic losses and waste, such as time spent repairing a grid that continuously fails due to recurring lightning, ice and wind storms, as well as indirect costs associated with power interruptions and poor power quality;
- 50 percent improvement in generation efficiency and environmental performance. Examples include source energy intensity (mmBTU consumed per MWh delivered), carbon intensity (lbs. of CO_2 equivalent emitted/MWh delivered) and solid waste landfilled (percent solid wastes recycled); and
- Measurable improvement in distribution system efficiency — MWh delivered to customer meters/MWh entering the system.

The benefit estimates assume the following market reforms:

- Empower, value and engage consumers through choice, price transparency, direct access to real-time usage data, net meterin, and payments for ancillary services. This includes providing consumers:
  - Open markets for retail electricity management services and consumer choice regarding their generation supplier. This provides consumers with access to cleaner and more efficient generation.
  - Price transparency and access to a wide array of dynamic pricing options enabled by advanced metering. This includes consumer access to real-time and time-of-use hourly pricing, which provides additional savings from price arbitrage.
  - Direct, secure access to real-time usage data enabled by advanced metering. This enables innovative applications and home automation to be coordinated with demand in real time.
  - Ability to cost-effectively net meter and interconnect local generation and receive full and fair value through feed-in tariffs for the electricity supplied. This includes both the physical and virtual aggregation of customer meters.
  - Payments for supplying ancillary services provided by the Independent System Operator. This includes providing access to day-ahead hourly markets and payments for demand response, capacity service and other ancillary services.
- Empower and engage local governments as partners in electricity system improvements. This includes local improvement plans; assurance that a portion of the collected rates are

spent locally; the ability to aggregate residents for community procurement; long-term, on-bill financing for local government-directed system improvements; and the authority to establish energy districts or microgrids.

The creation of a wider array of dynamic price signals and ancillary service payments will also encourage investment by entrepreneurial innovators as they work to provide technology and software solutions that enable consumers to realize the full potential of these investments and benefits.

Finally, grid modernization benefit estimates assume a new regulatory compact that rewards utilities and system operators for eliminating waste and improving measurable performance outcomes. This new regulatory compact includes implementing rules that maximize the value of grid investments by:

- Requiring that new customers pay their own way through a special rider that is applied over a limited period;
- Requiring greater detail on spending by voltage level and substation in: 1) operations and maintenance, 2) improvement spending, 3) repair cost, and 4) interruption impacts. These proposed new cost codes would not replace the two main cost codes currently used by utilities — capital and expense — but would be new sub-cost categories;
- Establishing a rider that enables large customers and local governments to invest in grid improvements or higher levels of reliability or power quality than are required by legislated standards;
- Requiring that system operators work with and coordinate grid improvements with local governments through specific local grid improvement plans;
- Establishing priorities for investment where vulnerable customers and poor-performing sections of the grid are improved first; and
- Leveraging the use of proven Six Sigma quality methods that focus on systems analysis to reveal small changes that have a large impact on performance, including investing in improvements that eliminate waste.

5 Investment Costs of Grid Modernization

This section outlines the investment opportunities and estimated costs for producing measurable improvements in system performance. The average estimated cost for the proposed electricity system upgrades is $400/household. This includes:

- Clean power supply investments in wind, combined cycle natural gas and other cleaner or renewable generation;
- Power delivery investments that focus on reliability and power quality, as well as enabling two-way power flow, interconnect, ancillary services and pricing markets; and
- End-use investments in the automation of home loads and intelligent software that produce conservation savings and enable consumers to generate revenue from providing ancillary services, as well as local clean distributed generation — leveraging buildings as a grid resource.

Table 3: Estimated Annual Grid Modernization Costs* per Residential Household

SECTION	TECHNOLOGY	ESTIMATED COST PER HOUSEHOLD, $/YEAR
Clean Power Supply Investment		~$80
Power Delivery Investment		~$150
5.2.1	Transmission and Area Distribution	$12
5.2.2	Local Distribution System or Microgrid Improvements**	$37
5.2.2.1	Local Substation Automation	$25
5.2.2.2	Circuit Loops with Smart Switches	$25
5.2.2.3	Undergrounding Local Cables	$50
End-Use Investment		~$165
5.3.1	Local Clean Power Supply	$46
5.3.2	Smart Meters	$20
5.3.3	Home Automation	$100
Approximate Annual Cost		~$400 / year

Source: llinois Institute of Technology. (2010). *Perfect Power at IIT* and Gellings, C. (2011). *Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid.* Palo Alto: Electric Power Research Institute.

*This costs represent capital cost amortized over a 15-year period.

**System investment categories based on EPRI report referenced above.

We based these estimates of grid modernization costs on data from the smart grid demonstration project, *Perfect Power* at IIT,[16] and a 2011 EPRI report on smart grid cost/benefit.[17] Home automation and smart meter costs are also based on general industry information and discussions with SmartLabs,[18] which shared information from their demonstration projects and Web-based automation store.

Energy efficiency costs and savings were assumed to be equal for the purpose of this evaluation and were therefore excluded.

5.1 CLEAN POWER SUPPLY INVESTMENT

Consumers are seeking to dramatically reduce the environmental impacts of generating electricity. This includes procuring more efficient and cleaner generation such as wind and high-efficiency, combined cycle, natural gas-fired generation, as well as solar photovoltaic (PV) and electricity storage.

It is anticipated that consumers, aggregators and state utility commissions will engage in performance-based, long-term contracts to procure an assumed 100 GW of cleaner generation that will displace older, inefficient coal, oil and natural gas generation at a cost of $3,000/KW or $300 billion nationwide, assuming that all of this cost is borne by the commercial and residential sectors. Based on the EPRI distribution of cost per customer class, the residential sector would bear about 40 percent of this cost and, amortized over 15 years, the annual cost to consumers would be $80 per household.

This new generation would complement the existing idle natural gas generation fleet of 300 GW, according to the U.S. Energy Information Administration's (EIA) *Annual Energy Outlook 2010*. The new generation discussed above, combined with idle existing natural-gas fired generation, should be sufficient to displace older, less efficient coal, oil and natural gas generation. This would allow the nation to dramatically reduce carbon emissions and increase generation efficiency.

5.2 POWER DELIVERY INVESTMENT

The electricity system can be transformed to significantly improve reliability, power quality and to accommodate local two-way power flow to facilitate local clean generation and customer price/demand response. LBNL reported that the bulk of power interruptions are caused by problems in the local distribution system. As a result, a larger portion of investment will be required at the local distribution system (local substations and circuits to customers).

The cost analysis provided herein indicates that, for a large utility, about 90 percent of the smart grid spending should be allocated to the local distribution system. Innovative Perfect Power designs such as Naperville, Ill., and the IIT (see Appendices A and B) reveal that interruptions could be reduced significantly by focusing on local distribution systems, including:

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[16] Illinois Institute of Technology. (2010). *Perfect Power at IIT*. Retrieved from http://www.iit.edu/perfect_power

[17] Gellings, C. (2011). *Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid.* Palo Alto: Electric Power Research Institute.

[18] SmartLabs Inc. (2010). Retrieved from http://www.smartlabsinc.com/index.html

1) The deployment of innovative technologies that allow substations to automatically isolate faults, restore service and re-route power. Today, utilities rely on manual fuses — like the old ones in homes — that open on a fault and must wait for utility crews to install a new one. Instead of everyone being served by the substation and thousands of residents losing power, with smart switches only a few hundred are out of service, and power to the rest of the residents is automatically restored;

2) The use of circuit looping with smart switches dispersed along looped circuits. Looping provides residents with power from two directions and smart switches sense and isolate faults to a very small area (i.e., a few homes). Instead of entire neighborhoods being in the dark due to a tree falling on a line, only a few customers are impacted;

3) Undergrounding cables to dramatically improve reliability and power quality, reduce repair costs, reduce tree-trimming costs and improve esthetics. Today's electricity system, for the most part, is exposed on overhead lines and poles. Very often when a storm rolls through a city, the power is knocked out. The typical response is to cut down all of the trees that threaten the power lines. Unfortunately, as cities try to become greener, they are planting more trees, resulting in a futile cycle of residents planting trees and utilities cutting them down. It is time for the electricity sector to invent more economical ways of moving the grid underground or to ground level;

4) The optimization of tap settings that reduce transformer efficiency losses. The savings can be reinvested into reliability or advanced meter upgrades; and

5) Advanced software, automation and control systems that can coordinate market pricing with end-use devices and utility system conditions to optimize reliability, power quality, efficiency and asset utilization. This network of technology is sometimes referred to as a master controller.

5.2.1 Transmission and Area Distribution

In a 2011 smart grid cost benefit report,[19] the Electric Power Research Institute (EPRI) identified the following investment categories and costs for the transmission and area substation systems. They also allocated about 40 percent of these costs to the residential sector. The total nationwide cost is $55 billion or $12 per residential customer, based on amortizing the costs over 15 years.

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[19] Gellings, C. (2011). *Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid.* Palo Alto: Electric Power Research Institute.

Table 4: Transmission and Area Distribution Investments

INVESTMENT CATEGORY	AVERAGE ESTIMATED COST, MILLIONS $	COMMENT
Dynamic thermal circuit rating	$170	Dynamic ratings increase the capacity of existing transmission lines by providing real-time transmission line ratings to system operators. This is accomplished by monitoring actual conductor tension and environmental factors.
Sensors	$2,250	Smart sensors in transmission corridors and substations will be able to monitor conditions in real time. That capability has many applications including safety, maintenance, asset management and risk assessment.
Short circuit current limiters	$580	This technology limits the magnitude of high-level fault currents to a level that can be managed by the distribution infrastructure's existing protection systems.
Storage	$0	The initiative removed this cost that will be borne by the private sector and paid for through market savings, not as an additional cost, $8 billion.
Flexible transmission	$4,600	"Flexible transmission" describes a wide range of technologies designed to give greater control over the transmission system in terms of power flow control, load sharing and many other possibilities.
PMU	$156	Phasor measurement units (PMU) draw in data about the transmission system's performance (such as voltage and current) at a speed of 30 times per second. These real-time measurements will allow for comprehensive monitoring and management of the electric system.
Communications to substations	$700	With the multitude of new evaluative technologies along the electric grid, there will have to be an upgrade to the information infrastructure leading to the substation to allow for the transmission of this data.
Communications for substations	$2,900	As the amount of data about the operations and performance of the electric system increases exponentially, substations will also need to be upgraded to process and use this information.
Relays and sensors IED	$6,050	Intelligent electronic devices (IED) refer to a number of technologies that are used to monitor and control various aspects of the grid, such as transformers and circuit breakers.
Cyber security	$3,700	Though the major benefits of a smart grid include automation, information collecting and widespread control, these features also make the system ripe for cyber attacks. Naturally, an enhanced method of security would be a must.

INVESTMENT CATEGORY	AVERAGE ESTIMATED COST, MILLIONS $	COMMENT
Back office enterprise software	$32,000	As with many other areas of the electric system, the increased amount of information and operations of a smart grid would require updates to the software utilities use to manage their operations.
ISO upgrades	$2,400	Just as utilities will need to upgrade their computers and communication devices to accommodate the added functionality of a smart gird, independent system operators (ISO) will also need to update their infrastructure.
Maintenance increase	$0	The initiative removed this cost based on an assumption that this would be offset by operational savings from automation, $15 billion
TOTAL	**$55,506**	This equates to about $12 per residential customer per year.

Source: Gellings, C. (2011). *Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid.*

5.2.2 Local Distribution System or Microgrid Improvements

EPRI identified the investment categories and costs outlined in Table 5 for the local distribution systems. Based on Perfect Power prototyping done by the Galvin Electricity Initiative, additional costs were identified associated with local substation automation, circuit looping, smart switches, and moving circuits underground/to ground level. These additional cost estimates are based on actual cost data from the IIT Perfect Power prototype.[20] EPRI also allocated about 40 percent of these costs to the residential sector. The total nationwide cost is estimated to be about $630 billion, or $150 per residential customer, based on amortizing the costs over 15 years.

Table 5: Distribution Improvement Costs

INVESTMENT CATEGORY	AVERAGE ESTIMATED COST, MILLIONS $	COMMENTS
EPRI Local Distribution Automation and Communications Costs		
Communications	$4,400	Communications allow the updated components of the smart grid to pass information back and forth, thus enabling the true potential of the system.
Current limiters	$2,300	Advanced current limiters can reduce the number of interruptions while at the same time securing a more steady and reliable flow of power.
Volt/Var control	$40,500	Voltage variation control is crucial for reducing loss and

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[20] Illinois Institute of Technology. (2010). *Perfect Power at IIT*. Retrieved from http://www.iit.edu/perfect_power

INVESTMENT CATEGORY	AVERAGE ESTIMATED COST, MILLIONS $	COMMENTS
		power quality events.
Remote control switch	$1,500	Remote control switches decentralize the manipulation of key components of the grid, cutting down on interruptions and increasing recovery time.
Direct load control	$1,800	Direct load control would enable the utilities to decrease non-essential electrical demand during peak hours to avoid the risk of overloading the system.
ElectriNet controller	$3,500	The ElectriNet controller allows the operator to coordinate electrical needs to work in concert with the smart grid for maximum efficiency and cost savings.
Operations and maintenance	$0	EPRI estimated an additional $8 billion in maintenance costs, which were assumed to be offset by operational and maintenance savings.
EPRI Subtotal	**~$54,000**	This equates to about $12 per residential customer per year.
EPRI Local Smart Switch Costs		
Head-end recloser	$16,000	Intelligent head-end reclosers allow for a more flexible, efficient power system by enabling instantaneous and time-overcurrent protection, better coordination with other devices and the ability for self-diagnosis. Assumed 70 percent penetration on circuits at a cost of $50,000 each.
Smart switch	$79,000	Smart switches can automatically adjust to isolate problems on the grid and instantly react with other smart technologies to reconfigure and adapt to changing needs. Assumed 55 percent penetration on circuits at a cost of $310,000 each.
Intelligent recloser	$14,500	Like many automated components of the smart grid, intelligent reclosers can seal off problems before they can spread system-wide and cause larger interruptions. Assumed 25 percent penetration on circuits at a cost of $125,000 each.
EPRI Subtotal	**~$109,500**	This equates to about $25 per residential customer per year.
IIT Prototype Improvements (See Sections 5.2.2.1 to 5.2.2.3)		
Substation automation	$116,000	This assumes $2,000,000 per substation based on the IIT prototype actual costs. This equates to about $25 per residential customer per year.
Looping	$46,500	EPRI estimated that there were 464,200 circuits nationwide at an estimated average cost of $100,000 to connect circuits in a looping or redundant configuration. This equates to about $10 per residential customer per year.
Smart switches	$70,000	This assumes adding two additional switches per circuit ($75,000 each) to the already budgeted reclosers and smart switch costs estimated by EPRI. This equates to about $15 per residential customer per year.

INVESTMENT CATEGORY	AVERAGE ESTIMATED COST, MILLIONS $	COMMENTS
Underground cables	$232,000	This assumes $1 million per circuit and undergrounding half of the total estimated circuits. This equates to about $50 per residential customer per year.
IIT Subtotal	**~$464,000**	This equates to about $25 per residential customer per year.
Total	**~$630,000**	This equates to about $150 per residential customer per year.

Source: Illinois Institute of Technology. (2010). *Perfect Power at IIT*.

5.2.2.1 Local Substation Automation

This category includes the costs for automated breakers and switches in the substation so that the substation bus can be supplied power from multiple feeds. The cost for substation automation is estimated at $2 million per substation. EPRI estimates about 58,000 substations total, or a cost of $25 per resident per year.

5.2.2.2 Circuit Loops with Smart Switches

Looping provides residents with power from two directions while sectionalizing smart switches sense and isolate faults to a smaller set of customers, reducing interruptions and outage duration. Costs in this category include the costs for additional conductors required to build loops out of radial feeds. It is assumed that some, but not all, existing conductors would have to be replaced. The exact cost will depend on the ratings and projected loads on the existing conductors.

The following assumptions were used to estimate additional costs for:

- Two additional intelligent reclosers or smart switches for each circuit at a cost of $75,000 for each of the estimated 460,000 circuits, or $15 per resident per year; and
- An estimated $100,000 per loop with an estimated 230,000 loops or $10 per resident per year (one for every two circuits).

5.2.2.3 Undergrounding Local Cables (Lower Voltage)

Some local governments are demanding that portions, if not all, of the local grid be moved underground and have offered to help pay for and coordinate planned undergrounding with other major infrastructure projects (e.g., streets, sewer, water and telecom). Undergrounding cables or moving cables to ground level can dramatically improve reliability, improve power quality, lower repair costs and improve aesthetics. Today's electrical system, for the most part, is exposed on overhead lines and poles, making the system very vulnerable to interruptions during a storm. Trimming or cutting down the trees that interfere with power lines is at odds with most residents' goals of a greener, more aesthetically pleasing neighborhood.

While undergrounding cables makes practical sense, cost is cited as an issue. However, as technology and methods for undergrounding improve, this objection diminishes. Trenchless technology, lower repair costs and improved reliability all must be factored in when determining the true rate of return of undergrounding. The costs will drop even further when this work is coordinated with other municipal sewer and street projects. Some cities are offering to install conduits with every major infrastructure project for use by the utility in the future. The cost for undergrounding cables is estimated at $1,000,000 per local circuit for 50 percent of the EPRI-estimated 460,000 circuits. Based on a 15-year rollout, this would cost each household about $50 per resident per year.

Ultimately, the electricity industry and the consumers it serves must decide if the electricity system will look the same in 100 years — exposed, unsightly and vulnerable. One way to look at this issue is to consider that our cities will be here for another 200 plus years. How much cable would need to be buried each year to move most of the system underground over 200 years? The industry is also at an inflection point, as tens of thousands of pole-mounted, smart-sectionalizing switches are planned that will make it even more costly to move the system to the ground level.

5.3 END-USE INVESTMENT

Consumers and innovators will respond to dynamic pricing signals, ancillary service payments and net metering for fair value and the new ability to easily interconnect and participate in electricity markets. This includes the introduction of a suite of new technology and software solutions. The result will be investment by consumers in technology and software that creates energy savings and generates revenue, including through ancillary services. In the new world of “apps” and “intelligent software,” it is likely that consumers will not have to take action to produce savings. Instead, advanced software will learn and adjust home operations to automatically minimize costs, energy use and associated emissions.

5.3.1 Local Clean Power Supply — Distributed Energy

Part of the grid modernization plan would include consumer and utility investment into local clean energy resources such as solar, biogas, electricity storage and gas-fired, distributed generation for backup power, both to avoid higher peak power costs and to provide ancillary services. This cost estimate includes 1 MW of distributed generation per substation at an average cost of $3,000/kW. EPRI estimated a total of 58,000 substations nationwide. The total cost would be about $46 per household annually over a 15-year period, assuming residential consumers bear 50 percent of the cost.

5.3.2 Smart Meters

Utilities may invest in smart meters if approved by the regulator. Otherwise, consumers may invest in smart meters supplied by entrepreneurs as part of a services solution that enables savings from participating in market pricing and conservation. EPRI estimated the cost of residential smart meters and support infrastructure at about $150 per residential customer. The total cost if financed over an assumed life of eight years is $20 per household.

5.3.3 Home Automation

A basic home-automation package is designed for conservation by targeting the more obvious, large loads in the home. This package would include programmable and controllable thermostats, Web-enabled energy management tools, controllers for switching off large loads, controllable dimmable lighting and intelligent apps or software that will automate the optimization of energy use and cost. The estimated cost is $800 per home for half of the meters in the subject area. The annual cost to consumers based on an assumed life of eight years is about $100 per household.

6 Benefits of Grid Modernization

This section estimates the potential benefits of modernizing the grid. The benefits are divided into three distinct categories: 1) direct bill savings, 2) indirect savings, and 3) future revenue potential. The total benefit is estimated at about $1,200 per year for a typical use household. While these projected savings are almost equivalent to the average annual bill of $1,200 (see Table 6), there is no implication that electricity will be free; the true potential of a modernized grid extends beyond the utility bill as indirect savings, avoided future rate increases and future revenue potential. Additionally, the benefits on public health, safety and security are significant and if effectively quantified would increase the benefits even more. Table 6 summarizes benefit categories and estimated potential annual cost savings from grid modernization.

Table 6: Summary of Estimated Annual Savings per Residential Household

SECTION	CATEGORY	ANNUAL SAVINGS/YR.
6.1	**Direct bill savings (including avoided rate increases)**	**$585**
6.1.1	Electricity consumption savings	$125
6.1.2	Dynamic pricing, time-of-use savings and shifting peak demand	$110
6.1.3	Avoided new capacity costs	$130
6.1.4	Improved generation efficiencies	$200
6.1.5	Reduced transmission and distribution losses	$20
6.2	**Indirect savings**	**$400**
6.2.1	Improved reliability and power quality	$400
6.3	**Future revenue potential**	**$250**
6.3.1	Revenue for providing electricity and ancillary services	$140
6.3.2	Emission reduction credits	$110
	TOTAL BENEFIT	**$1,200**
6.4	Public health, safety and homeland security	Significant

See Appendix D: Benefit Calculations, for information on how these numbers were derived.

Note: The savings shown will be utilized to offset investment in system improvements, which means that consumers may not see all or most of these savings until the investments are paid off. Furthermore, some of the savings are indirect costs, which will not be reflected on the customer bill. Finally, these savings are based on specific smart grid investments that produce measurable improvements in performance, as well as market reforms that empower and value customer and local government investment and action (see Section 4).

- **Direct bill savings —** This category refers to reductions on the monthly bill and avoided costs or rate increases (for example, the cost of building new generation and distribution capacity, which is added to existing rates). Many utilities are seeking significant rate increases that attempt to recoup costs of meeting growing demand.
- **Indirect savings —** This category factors in all of the largely unmeasured impacts of the current electricity grid, such as consumer and business economic losses that result from interruptions and power quality fluctuation.
- **Future revenue potential —** For this category, there is the expectation that consumers could receive income from supplying ancillary services and electricity to the modernized grid. This also includes increased household income from new jobs generated through grid investment.

Finally, it is important to set a baseline of electricity spending and consumption in order to provide a point of comparison. These numbers are used throughout this research paper as the basis for many calculations.

Table 7: Baseline Electricity Consumption and Spending[21,22]

Number of U.S. residential customers	125,000,000
Average annual consumption	11,040 kWh
Average cost per kWh	$0.114
Average annual bill	$1,259

Source: U.S. Energy Information Administration, U.S. Department of Energy. (2010.) *Annual Energy Outlook 2010* and Residential Average Monthly Bill by Census Division, and State.

6.1 DIRECT BILL SAVINGS

The U.S. electricity system is wasting significant amounts of energy and capital (see Section 3). These costs are being passed on to consumers. If the system continues to operate inefficiently, significant increases in peak load will also lead to rate increases or additional costs that will be added to current bills. The savings discussed herein include both reductions in current costs as well as reductions in future increases to electricity costs.

Direct bill savings depend upon the assumed market reforms and changes to electricity system rules as described in Section 4.

The savings will come from:

- Electricity consumption savings and conservation;
- Demand reduction and shifting of time of use;
- Avoided new generation and distribution capacity additions;

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[21] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A8.

[22] U.S. Energy Information Administration, U.S. Department of Energy. (2010). Table 5: Residential Average Monthly Bill by Census Division, and State. Retrieved from http://www.eia.doe.gov/cneaf/electricity/esr/table5.html

- Choosing more efficient generation sources; and
- Reductions in overall system losses resulting from system operational advancements.

Today, consumers have no idea that the real cost of electricity generation during peak periods can exceed $200/MWh while costing almost nothing during the night.[23] Most consumers across the country pay the same price for electricity at all times throughout the day and year. As a result, there is no price response and peak demand just keeps growing.

Most efforts to date have focused on event-based pricing (e.g., utilities request a few times a year to reduce usage for a small payment) and not market-based pricing (e.g., hourly and daily pricing that offers consumers the opportunity for substantial savings). Learn more about event and market based pricing in the Galvin Electricity Initiative report, “Maximizing Consumer Value Through Dynamic Pricing: A Suggested Approach for Regulators.”[24]

A smart grid would convey market-based prices to consumers that reflect the true cost of generating and delivering that power, including greater use of dynamic pricing and payments for ancillary services. A smart grid would automatically provide real-time price signals to each household’s appliances and devices, which can — at the homeowner’s discretion — take steps to operate when electricity rates are at their lowest.

A smart grid would also pay consumers for supplying ancillary services. For example, a smart grid would enable and encourage customers to generate their own power through solar or electricity storage. These technologies not only benefit the consumer, but also take some of the burden off of the utility by slowing peak demand growth and eliminating the need for investments in at least a portion of the projected system expansion costs, generation and distribution.

6.1.1 Electricity Consumption Savings

Electricity savings could be realized in part by avoiding consumption through smart home and appliance technologies, tools and techniques. Once consumers and businesses invest in energy-saving technologies, energy savings can be realized. An example is that once a home automation system is installed, it can be used to turn off lights and change thermostat set points when the occupants are not at home. One specific example is the application of building automation equipment for small businesses. Lutron Electronic, Inc. reported 40 to 60 percent reductions in lighting loads, without adversely affecting productivity.[25]

Though several studies have been prepared recently on home automation pilots, we have not found any reports that analyze the permanence of energy savings over an extended period of time from home automation. Most studies have focused on demand response impacts and responses to specific events on the grid. We plan to conduct studies based on home automation pilots, but until results are more definitive, we assume that the long-term savings would be 10 percent of the annual electric bill. This includes savings from automation of lighting, HVAC and a few major plug loads. The EIA’s *Annual Energy Outlook* indicates that the average national

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[23] PJM. (2009). *Real Time.* Retrieved from http://www.pjm-miso.com/markets/energy-market/real-time.html

[24] Galvin Electricity Initiative. (2011, January). *Maximizing Consumer Value Through Dynamic Pricing: A Suggested Approach for Regulators.* Retrieved from http://www.galvinpower.org/sites/default/files/DynamicPricing_0110.pdf

[25] Lutron. Commercial Solutions: Energy Savings. Retrieved from http://www.lutron.com/Residential-Commercial-Solutions/Commercial-Solutions/Pages/CommercialEnergySavings.aspx

electricity price is 11.4 cents per kWh. The EIA estimates the average annual electricity consumption is 11,040 kWh per household.[26] The average annual cost savings is estimated to be $125 per year per household.

It is also important to note that this reduced electricity consumption from the efficiencies of an updated system will create a new paradigm moving forward. Our calculations will now refer to the adjusted annual consumption of 9,900 kWh rather than the current data from the EIA (Table 7).

Table 8: Adjusted Average Consumption

Current estimated annual average consumption	11,040 kWh
10 percent reduction	1,104 kWh
Savings per household at 11.4 cents/kWh	~$125
Adjusted household usage	~9,900 kWh

See Appendix D: Benefit Calculations, for information on how these numbers were derived.

6.1.2 Dynamic Pricing, Time-of-Use Savings and Shifting Peak Demand

Energy savings include the potential for reducing peak demand by shifting electricity consumption from peak periods to off-peak periods. Different rate structures can be used to incentivize consumers to change consumption use and patterns.[27] Examples include time-of-use rates and various types of dynamic pricing such as real-time pricing. A modern grid strategy includes providing consumers with dynamic pricing through smart meters, allowing consumers via their home automation systems to respond to price signals. One report suggested that peak load could be reduced by 20 percent using these techniques.[28]

The Initiative performed an analysis for the Illinois Institute of Technology that indicated that the school could save 25 percent of their electric costs just by switching to real-time from fixed-price, third-party rates. This was based on IIT's 2006 electricity procurement contract, 2006 real-time rates from PJM in ComEd's territory and IIT's 2006 hourly electricity consumption. These savings could be increased for residential customers, as the hourly residential peak consumption is often later than the grid's peak, based on the Initiative's observations of actual in-home hourly consumption. Assuming a conservative 10 percent reduction of electric costs using the reduced usage from Section 6.1.1 — or 9,900 kWh — the average household would save about $110 per year.

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[26] U.S. Energy Information Administration, U.S. Department of Energy. (2010). Table 5. Residential Average Monthly Bill by Census Division, and State. Retrieved from http://www.eia.doe.gov/cneaf/electricity/esr/table5.html

[27] Galvin Electricity Initiative. (2011, January). *Maximizing Consumer Value Through Dynamic Pricing: A Suggested Approach for Regulators.* Retrieved from http://www.galvinpower.org/sites/default/files/DynamicPricing_0110.pdf

[28] Hammerstrom, D., Ambrosio, R., Brous, J., Carlon, T., Chassin, D., DeSteese, J., et al. (2007). *Pacific Northwest GridWise Testbed Demonstrations Projects: Part I.* Olympia Peninsula Project, PNNL-17167. Richland: Pacific Northwest National Laboratory.

6.1.3 Avoided New Capacity Costs

As mentioned, dynamic and market-based pricing and home automation can provide reductions in both total electricity consumption and peak demand. This can translate into savings for consumers in other areas, as these impacts will reduce peak generation, transmission and distribution capacity requirements. Additionally, smart grid technologies can improve and optimize transmission and distribution utilization through the expanded use of sensors, controls and optimization software. A National Renewable Energy Laboratory report on distribution system costs methodologies states:[29]

> "While generating costs may experience a decline through technological gains in efficiency, costs of the distribution system have no comparable innovations in the wings. Average aggregate annual investments of more than $6.4 billion per year were made by the 124 utilities in our study. This translates to an *annual revenue requirement increase per year* on the order of $1 billion to $1.5 trillion. This is a significant cost and deserves the attention of regulators and the application of appropriate least-cost strategies. To put this in context, the 124 companies in our study had an average revenue during the 1995–1999 period of just more than $134 billion."

According to the EIA,[30] the total U.S. generation capacity is 960 GW.[31] Fossil fuel generation is expected to grow by about 100 GW by the year 2035 to meet growing peak demand. This does not include power plant retirements. If, through grid modernization, consumers could permanently reduce total grid peak demand by 10 percent, the U.S. peak demand could be reduced by about 100 GW.[32] This means that consumer empowerment could virtually eliminate the need for new fossil fuel capacity. The avoided total generation and distribution capacity cost estimate is $130/customer/year based on the assumptions and results shown in Tables 9 and 10.

6.1.3.1 Avoided New Generation Capacity Costs

We estimated the capacity savings of avoided fossil fuel generation, based on a total 10 percent reduction in system peak demand, or 100 GW. If a new power plant costs $2,200/kW or and financing costs about 5 percent over 30 years, savings would equal about $14 billion annually or $80 per average U.S. household, assuming 50 percent of the commercial and industrial savings are passed on to consumers.

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[29] Shirley, W., Cowart, R., Sedano, R., Weston, F. W., Harrington, C., & Moskovitz, D. (2001). *Distribution System Cost Methodologies for Distributed Generation, NREL/SR-560-32500.* National Renewable Energy Laboratory. Gardiner: The Regulatory Assistance Project.

[30] U.S. Energy Information Administration, U.S. Department of Energy. (2011). *Annual Energy Outlook 2011,* Table A9.

[31] U.S. Energy Information Administration, U.S. Department of Energy. (2008). *Existing Generating Units in the United States by State, Company and Plant 2008.* Retrieved from http://www.eia.doe.gov/cneaf/electricity/page/capacity/capacity.html

[32] This estimate assumes that the residential portion of peak capacity is proportional to the ratio of residential consumption over total U.S. consumption. Total U.S. consumption was assumed to be 3,713 GWh and residential consumption was assumed to be 1,392 GWh based on U.S. Department of Energy, U.S. Energy Information Administration, Table 5.1: Retail Sales of Electricity to Ultimate Customers: Total by End-Use Sector, 1996 through August 2010, ftp://ftp.eia.doe.gov/electricity/epm/02261011.pdf

Table 9: Estimate of Avoided New Generation Capacity Costs

ASSUMPTIONS	
Avoided capacity, GW	100
New plant cost, $/kW	$2,200
Interest rate	5%
Term, years	30
RESULTS	
Total cost	$220,000,000,000
Annual cost	$14,300,000,000
Avoided generation capacity costs per kW, $/kW	0.004
Total U.S. Residential Customers[33]	125,000,000
Annual savings per household	**~$80/year**

See Appendix D: Benefit Calculations, for information on how these numbers were derived.

6.1.3.2 Avoided New Delivery Capacity Costs

The Brattle Group estimates that $1.5 to $2 trillion needs to be spent on the U.S. utility delivery infrastructure expansion over the next 20 years to meet the projected demand growth.[34] Assuming that 10 percent of this investment can be avoided and that 50 percent of the commercial and industrial savings are passed on to consumers, this translates to a delivery reduction cost of approximately $50 per household per year.

Table 10: Estimate of Avoided New Delivery Capacity Costs

Total U.S. utility infrastructure improvement cost	$1,500,000,000,000
Avoided cost	$150,000,000,000
Interest rate	5%
Term, years	30
Annual cost	$10,000,000,000
Avoided infrastructure capacity costs per kW, $/kW	$0.0026
Total U.S. Residential Customers	125,000,000
Annual savings per household based on consumption.	**~$50/year**

See Appendix D: Benefit Calculations, for information on how these numbers were derived.

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[33] U.S. Census Bureau (2010). *State and County Quickfacts*. Retrieved from http://quickfacts.census.gov/qfd/states/00000.html

[34] Chupta, M., Earle, R., Fox-Penner, P., & Hledik, R. (2008). *Transforming America's Power Industry: The Investment Challenge 2010-2030.* The Brattle Group. Note that the Brattle Group also estimates that 214 GW of new generation will be required by 2030 at a cost of $697 billion. This works out to a cost of $3,257 per installed kilowatt.

6.1.4 Improved Generation Efficiencies

The total U.S. fossil fuel consumption for electricity is about 37 quadrillion BTU.[35] Based on a total electricity supply of 3,700 million MWh,[36] the overall electricity system efficiency is 35 percent, wasting about 65 percent of the input energy or 24 quadrillion BTU. Based on new smart grid system rules that allow consumers the choice to procure generation with higher efficiencies and allow vertically integrated utility commissions to pursue competitive higher efficiency generation, we assume a 50 percent improvement in efficiency to 53 percent. This results in a savings of about 12 billion mmBTU or $37 billion annually at $3/mmBTU. The savings estimates in Table 11 calculations use EIA's *Annual Energy Outlook* usage data for each sector and assume that 50 percent of the commercial and industrial savings is passed on to consumers. The average savings is estimated at about $200 per household annually.

Table 11: Generation Efficiency Savings

	USAGE, MILLION MWH	MMBTU SAVINGS	TOTAL SAVINGS AT $3/MMBTU	SAVINGS PER HOUSEHOLD
Residential	1,380	4,600,000,000	$13,700,000,000	$110
Commercial	1,350	4,500,000,000	$13,400,000,000	$54
Industrial	980	3,200,000,000	$9,700,000,000	$39
Total	**3,710**	**12,300,000,000**	**$36,900,000,000**	**~$200/year**

See Appendix D: Benefit Calculations, for information on how these numbers were derived.

6.1.5 Reduced Transmission and Distribution Losses

Smart switching and peak demand reduction technologies can potentially reduce transmission and distribution losses. The EIA estimates current (2008) transmission losses to be about 7 percent.[37] The EIA estimated that these losses could be reduced to 5.3 percent through the Smart Grid American Recovery and Reinvestment Act (ARRA) grants, which generally provide for only partial modernized grid deployments. This 1.7 percent reduction in losses translates to a reduction in generation costs incurred by consumers. Using transmission and distribution (T&D) and generation costs by sector from Table A8 in the *Annual Energy Outlook 2010*, the average savings per household is about $20 annually. This assumes only 50 percent of the commercial and industrial savings are passed on to consumers.

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[35] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A2.

[36] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A8.

[37] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* p.10.

Table 12: Estimate of Annual Savings Due to Reduced T&D Losses

Average T&D costs	$31 /MWh
Residential generation savings = 1.6%*($112-$31/MWh)*1,380 million MWh	$1,800 million
Commercial generation savings = 50%*1.6%*($103-$31/MWh)*1,350 million MWh	$785 million
Industrial generation savings = 50%*1.6%* ($68-$13/MWh)*980 million MWh	$293 million
Total savings	$2,900 million
Total number of residential customers	125 million
Annual cost savings per household	**$23/year**

See Appendix D: Benefit Calculations, for information on how these numbers were derived.

6.1.6 Reduced Operating Costs

Grid modernization will enable utilities to eliminate operations waste and inefficiency. This includes eliminating repair costs associated with restoring power, as well as automating numerous manual operations from meter reading to customer services. For the purposes of this analysis, the operations savings were offset by increased preventive maintenance and increased operating costs associated with maintaining all of the new smart technology. Further analysis is warranted to quantify the potential consumer savings associated with eliminating operational waste.

6.2 INDIRECT SAVINGS

Focusing solely on the on-bill savings would ignore the majority of what a modernized grid can offer in terms of savings based on accounting for the economic and societal losses associated with electricity safety, interruptions and power quality events. While these issues do not appear on a monthly bill, they can cost billions of dollars per year and take a tremendous toll on residential, commercial and municipal resources (see Section 3).

> These savings are based on the assumptions that smart grid investments produce at least a 50 percent improvement in safety, reliability and power quality — putting the U.S. on par with European performance.

Table 13: Comparison of Average National Reliability Metrics with U.S. Competitors

COUNTRY	SAIDI	SAIFI
Germany	23	0.5
Denmark	24	0.5
Netherlands	33	0.3
Italy	58	2.2
France	62	1.0
Austria	72	0.9
UK	90	0.8
Spain	104	2.2
United States	240	1.5

Source: Council of European Energy Regulators ASBL (2008). 4th Benchmarking Report on the Quality of Electricity Supply, Brussels:CEER.

Table 13 shows that U.S. electricity reliability is not keeping pace with performance in Europe, placing our country at an economic disadvantage. Specifically, the U.S. falls behind in measures of:

- SAIDI (System Average Interruption Duration Index, in minutes) — the average number of minutes a customer is without power; and

- SAIFI (System Average Interruption Frequency Index) — the average number of interruptions a customer experiences.

One of the reason electricity system operators cannot justify investment is that they do not account for the injuries, deaths or economic losses to families and businesses when the power goes out. Furthermore, system operators are not rewarded for tracking and eliminating operational waste and lost productivity within the obsolete electricity system.

6.2.1 Improved Reliability and Power Quality

One of the major areas where a modernized grid would reduce costs is reliability and power quality. Electricity has become such a crucial part of our everyday lives that when interruptions do occur, the financial impact can be enormous. Beyond the repair crews required by the utility to solve the problem, lost productivity, loss of goods or data, accidents related to the interruption and customer reimbursements can all drive the true cost of an interruption to staggering heights. Because reporting on interruption costs is so deficient, the actual price of an interruption can only be estimated.

LBNL analyzed the assumptions made in prior estimates and developed their own framework for assessing the cost of interruptions.[38] LBNL estimated the economic losses of unreliable electricity to be approximately $80 billion per year, but it could be as high as $130 billion per year, not including power quality events. Reports by EPRI and the U.S. Department of Energy have estimated the cost of electricity interruptions at between $30 billion and $400 billion per year[39] — quite a large range.

Based on these figures, it is estimated that the national average cost of interruptions to consumers and businesses of $150 billion per year. Assuming that smart grid investments will improve reliability and power quality performance by 50 percent, we estimate $75 billion in indirect savings for consumers. This was converted to an average annual household savings using the following methods and assumptions:

- Average Indirect Cost Savings[40] = $75 billion per year
- Average Annual kWh Consumed[41] = 3,710 billion KWh
- Total number of residential customers = 125 million

Assuming 50 percent of the commercial and industrial costs gets passed on to consumers, this works out to an average household cost of interruptions of about $400 per year. This cost represents the average direct cost of interruptions experienced by households and the indirect

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[38] LaCammare, K. H., & Eto, J. H. (2004). *Understanding the Cost of Power Interruptions to U.S. Electricity Consumers, LBNL 55718.* Ernest Orlando Lawrence Berkeley National Laboratory, Energy Analysis. Berkeley: University of California Berkeley.

[39] Primen. (2001). *The Cost of Power Disturbances to Industrial and Digital Economy Companies.* Consortium for Electric Infrastructure to Support a Digital Society. Madison: EPRI.

[40] Lawton, L., Sullivan, M., Van Liere, K., Katz, A., & Eto, J. (2003). *A Framework and Review of Customer Outage Costs: Integration and Analysis of Electric Utility Outage Cost Surveys, LBNL 54365.* Population Research Systems, LLC and Ernest Orlando Lawrence Berkeley National Laboratory. Berkeley: University of California Berkeley.

[41] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A8.

costs of goods and services levied to households, as manufacturers and service providers will pass costs of interruptions on to their customers.

Table 14: Interruption Cost Indirect Savings

	USAGE, MILLION MWH	INTERRUPTION COST SAVINGS PER SECTOR, BILLIONS $	SAVINGS PER HOUSEHOLD
Residential	1,380	$27	$216
Commercial	1,350	$27	$108
Industrial	980	$21	$84
Total	**3,710**	**$75**	**~$400/year**

See Appendix D: Benefit Calculations, for information on how these numbers were derived.

Variations in power quality can also take a costly toll on the community. Momentary dips and changes in power quality can wreak havoc in data centers and other businesses that are dependent on a steady, continuous flow of power for operation. Currently most utilities are not required to track these momentary variations, and more research is needed to determine their true financial impact.

6.3 FUTURE REVENUE POTENTIAL

Grid modernization has the potential for allowing consumers to earn revenue for providing valuable services. Consumers can only earn revenue if:

1) They are provided with access to all Independent System Operator ancillary service payments such as day-ahead hourly markets, demand response, capacity and power quality services.
2) They can cost-effectively interconnect with the grid and net-meter at market value for the electricity produced. Other market reforms that increase the revenue for customers include:
    a. Rollover net-metering for excess generation in a month, trued up annually.
    b. Physical net-metering for multi-tenant buildings that provide for building efficiency upgrades and solar capability additions, while gaining market power for procurement. Building energy improvements can be added to each tenant's bill.
    c. Virtual net-metering, which allows buildings in close proximity to each other to aggregate meters for procurement and sharing local clean generation.

6.3.1 Revenue for Providing Electricity and Ancillary Services

As smart grid technologies progress and electricity markets mature, consumers can become both ancillary service providers and electricity suppliers. Ancillary services can include demand response, day-ahead markets, capacity markets and power quality services. Based on the estimates outlined below, consumers could save/earn an average of $250 per year per household if empowered to become market participants. Consumers can generate savings/revenue by:

- Participating in market demand response, where consumers can receive $5 to $20 per kW per month for agreeing to reduce peak demand when called upon in the New York, PJM, Florida and New England independent system operator areas. Assuming a home could reduce peak demand by 15 percent or 0.5 kW, the homeowner could earn $30 to $120 a year in revenue;
- Participating in a utility curtailment program or event-based demand response where the consumer can be paid $20 to $40 a year to allow the utility to curtail major loads to protect the grid during a momentary system imbalance;
- Participating in day-ahead markets whereby a consumer sells a fixed price supply contract in the day-ahead markets. Assuming a home could reduce peak demand by 15 percent, or 0.5 kW, the homeowner could earn 0.5 kW times 1,000 hours times an average 8 cents/kWh difference between the day-ahead and the contact price, or $36 annually; and
- Constructing home solar photovoltaic and wind systems, which reduce electricity costs and create a possible revenue source. The economic payback varies widely across the country depending upon the policy rules and cost of electricity. Solar PV prices have been falling and the economics are improving. For the purposes of this study, no savings are projected.

6.3.2 Emission Reduction Credits

The U.S. EIA's *Annual Energy Outlook*[42] summarizes major emissions from electricity generation as 2.4 billion tons of carbon dioxide (see Table A18 in the report), 7 million tons of sulfur dioxide and three million tons of nitrogen oxide at estimated costs of $20 (assumed), $1,500 and $3,000 per ton over the next decade, respectively (see page 82 in the report). The total annual cost is estimated at $68 billion. If consumers are allowed to receive credit for conservation that curbs fossil fuel generation, they could possibly receive an income stream for reducing emissions. The savings shown below assume a 30 percent reduction in emissions based on improvements in conservation, generation efficiency and reductions in generation emissions. The revenue per kWh for a 30 percent reduction is $68 billion times 0.3 divided by 3,713 million MWh, or 0.5 cents/kWh.

It is also assumed that commercial and industrial users pass on 50 percent of the revenue to consumers in the form of lower costs of services. A consumer that switches from coal-fired generation to combined cycle gas generation reduces emissions by 60 to 80 percent.

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[42] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Tables A1 – A20.

Table 15: Emissions Reduction Revenue/Savings

	USAGE, MILLION MWH	EMISSIONS REDUCTION REVENUE, BILLIONS $	REVENUE/SAVINGS PER HOUSEHOLD
Residential	1,380	$7.5	$59
Commercial	1,350	$7.4	$29
Industrial	980	$5.3	$22
Total	**3,710**	**$20.2**	**~$110/year**

See Appendix D: Benefit Calculations, for information on how these numbers were derived.

6.4 PUBLIC HEALTH, SAFETY AND HOMELAND SECURITY

Significant improvements to grid reliability, power quality and stabilizing of the grid from inadvertent interactions or terrorist attacks will protect safety. Electricity is a significant life safety hazard for grid operators and consumers.

Australia appears to be the only country that requires utilities to report public deaths or injuries caused by power interruptions or interactions with the distribution system.[43] For comparison purposes, the railroad industry reports all deaths or injuries caused by trains in accordance with the Federal Railroad Administration's Accident/Incident Reporting Requirements. The text box on page 37 provides several examples of power line interaction deaths for consumers reported by the media.

Consistent reporting is needed to quantify the non-occupational deaths from contact with power lines, as well as other deaths related to power interruptions (e.g., loss of cooling, loss of heating, fires from candles used for light and loss of life-support systems).

Self-healing attributes of transmission and distribution systems will help improve system safety. This includes protecting exposed system components and enabling significantly faster de-energization of downed power lines. Smart sectionalizing switches and cyber security will prevent both inadvertent accidents and terrorism. In addition, local distributed generation can be strategically deployed to provide backup power when substation supply is lost. Specific safety improvement examples include,

- Smart switches that isolate downed power lines.
- Underground local distribution systems would prevent interactions with local overhead power lines, a major cause of non-utility worker electrocutions.
- Communicating to local residents the danger associated with overhead power lines could prevent accidents. This includes outlining what to do when you encounter a downed power line.

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[43] Australian Electrical Regulatory Authority Council. (2005 – 2006). Electrical Incident Data: Australia and New Zealand. Retrieved from http://www.erac.gov.au/downloads/Erac%202005-2006.pdf

6.4.1 Direct Contact with Power Lines

In terms of safety, utilities track and report deaths and injuries of workers in accordance with standards set forth by the Occupational Safety and Health Administration (OSHA). This agency also tracks deaths related to workers from other industries that come in contact with power lines. The U.S. Department of Labor's Bureau of Labor Statistics reports that about 100 people each year die from contact with power lines and more than half are not from the utility industry. However, this does not include non-occupational deaths from contact with power lines. Tables 16 and 18 provide a summary of work-related, electricity-related deaths from 1992 to 2003.[44] Table 17 reveals that contact with overhead lines is a leading cause of non-electricity worker deaths, totaling 630 over 12 years.

Table 16: Worker Death Statistics by Trade

TRADE	# DEATHS	% OF TOTAL
Electrical workers	586	34%
Construction laborers	274	16%
Carpenters	97	6%
Non-electrical supervisors	86	5%
Roofers	72	4%
Other trades	600	35%
Total	**1,715**	**100%**

Source: McCann, M. (2006). Why Are So Many Construction Workers Being Electrocuted?

Table 17: Worker Death Statistics by Cause

CONTACT WITH	ELECTRICAL WORKERS	OTHER CONSTRUCTION WORKERS
Electrical wiring/equipment	341 (58%)	272 (24%)
Overhead power lines	201 (34%)	630 (56%)
Machinery, appliances	25 (4%)	126 (11%)
Other	19 (3%)	101 (9%)
Total	**586 (99%)**	**1,129 (100%)**

Source: McCann, M. (2006). Why Are So Many Construction Workers Being Electrocuted?

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[44] McCann, M. (2006). *Why Are So Many Construction Workers Being Electrocuted?* Retrieved from http://www.elcosh.org/en/document/557/d000539/why-are-so-many-construction-workers-being-electrocuted%253F.html

6.4.2 Outage Related Deaths and Injuries

When an area of a city loses power, police and firefighters must be diverted from protecting neighborhoods to recovery operations and to make sure citizens are safe. When the power fails, many residents turn to candles for light and generators for power — both of which introduce an inherent danger. Electricity is critical to residential safety — heating, cooling or medical support and outages tax first responders. Similarly, the transportation infrastructure is compromised as traffic lights go dark and police are reassigned to direct traffic.

The Names Behind the Numbers

March 27, 2008 — Cleveland, Ohio

6-year-old **Nathan Kenemore** came into contact with an un-insulated, high-voltage power line as he was climbing the branches of a tree.

Source: Wineka, M. (2008, September 17). *Power company sued in death of 6-year-old*. Retrieved from Salisburypost.com: http://www.salisburypost.com/Area/091708-electrocution-lawsuit

February 4, 2009 — Galesburg, Ill.

Patricia Higgins, 57, came upon an accident and got out of her van to help. She lost her balance in a snow-filled ditch and grabbed a support wire. A downed power line from a broken pole was on the support wire and Higgins was electrocuted.

Source: Taylor, J. (2009, January 30). *Woman electrocuted helping at crash scene*. Retrieved from Galesburg.com: http://www.galesburg.com/news/x977238883/Woman-electrocuted-helping-at-crash-scene

June 2, 2009 — Allegheny, Pa.

Carrie Goretzka, a 39-year-old mother of two, died after a power line fell on her in her backyard.

Source: Riely, K. (2009, July 14). *Allegheny Energy sued over Irwin woman's death*. Retrieved from Pittsburgh Post-Gazette: http://www.post-gazette.com/pg/09195/983734-59.stm

July 25, 2010 — Lancaster County, Pa.

Sheila Coldren, 53, was electrocuted by a downed power line at her home.

Source: Robinson, R. (2010, July 26). *Police ID woman killed in storm*. Retrieved from Lancaster Online: http://lancasteronline.com/article/local/269895_Police-ID-woman-killed-in-storm.html

January 16, 2011 — San Bernadino, Calif.

Steven Vego, 43, **Sharon Vego**, 42, and **Jonathan Cole**, 21, died after contacting a downed power line. Sharon and Jonathan were killed trying to free Steven. Rescue crews waited at the scene for more than an hour for power to be interrupted.

Source: Li, S., & Allen, S. (2011, January 15). *Downed power line kills 3 in San Bernardino*. Retrieved from Los Angeles Times: http://articles.latimes.com/2011/jan/15/local/la-me-three-dead-20110115

7 Conclusions

The full benefits of an improved electricity grid can far exceed the grid modernization costs — a typical household realizing a potential benefit of $1,200 with an estimated cost of $400. These investments improve the grid by eliminating waste, reducing costs, reducing interruptions, and improving societal and economic conditions. A customer can realize these benefits directly on their monthly bill, indirectly through reduced power interruptions and through revenue for providing ancillary grid services.

The costs outlined do not necessarily mean that electricity will be free. Instead, savings will be used to offset investment costs. Considering the amount of capital, resources and energy that is wasted in the current system, there are a lot of savings that can be reallocated to pay for the efficiency improvements. Therefore, consumers may not see all or most of these savings until the investment is paid off.

Likewise the benefits estimated depend upon market reforms that empower and enable consumers and local governments to participate and invest as partners with system operators and owners. The system is so vast and has long suffered from under-investment that updating it with modern technologies will require investment by the public and private sectors to collaboratively improve performance.

> “Technology has no inherent value; technology defines its value by what result it achieves in terms of improving the customer experience.”
>
> *— Robert Galvin,*
> *as CEO of Motorola*

The wide-ranging benefits of a modern grid are far more expansive than on-bill savings but there is no way around the fact that comprehensive grid modernization requires large commitments of resources. However, no investment of this magnitude can be fully evaluated on its price tag alone. With reduced emissions and environmental impacts, public health and safety will improve for future generations and the job-creation prospects of a burgeoning energy industry will keep America competitive with other industrialized nations. Consumers, local government officials, entrepreneurs and system operators must work together to initiate the changes and prioritize grid modernization to realize the financial and environmental benefits.

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Appendix A: Achieving Perfect Reliability

One municipality that was able to dramatically improve the reliability of their electricity system and reduce the cost of power for their customers is the Chicago suburb of Naperville, Ill.

In the early 1990s, Naperville's municipal utility was not performing well, and the city council held a vote on whether to sell it to the larger areawide utility, ComEd. At this time, three or four customer outages per year were common. The sale was defeated by one vote in the city council, and the municipal utility leadership decided instead to pursue perfect power reliability without raising costs. They started applying the concepts behind what is today called Six Sigma or quality improvement. Over a period of almost 20 years, and without raising rates, the local grid was transformed into one of the most reliable suburban grids in the country.[45]

In fact, Naperville maintained lower rates than ComEd, even while investing tens of millions of dollars a year into continuous improvement. Their first step was to install a Supervisory Control and Data Acquisition (SCADA) system so that they could evaluate loading on their circuits and develop plans for problem areas. Over the course of the next decade, they ran power lines underground and implemented a new "high-reliability design" that involves circuit looping and deployment of multiple sectionalizing smart switches on each loop. This allowed faults to be sensed and isolated, minimizing or eliminating outages. Later on in their process, Naperville started using their SCADA, combined with a Geographic Information System (GIS), to pinpoint problems, which allowed their operators to either fix problems remotely or dispatch linemen to the problem areas quickly.

> Naperville was able to invest hundreds of millions into Perfect Power by requiring new developments to pay their own way. Prior to this policy change, system expansion was siphoning off most of the improvement funding. In addition, they focused on early changes that reduce their O&M budgets, leaving more money for investment in improvement. They established an ethic that they would not raise rates but instead find innovative ways to eliminate waste and shift spending to investments that produced meaningful and dramatic outcomes.

For utilities in growing areas, it can be difficult to invest in the existing system, as a large portion of transmission and distribution capital allocations are used for system expansion. Naperville alleviated this problem by using a "pay your own way" rate mechanism, which required new customers to pay for any system changes needed to support new development. Cost recovery for new development is accomplished via a temporary rate rider (e.g., one cent per kWh) that is levied until all utility costs are recovered, usually in three to five years.

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[45] Galvin Electricity Initiative. (2010, April). *Naperville Case Study.* Retrieved from http://www.galvinpower.org/galvin-conducts-naperville-smart-grid-initiative-case-study

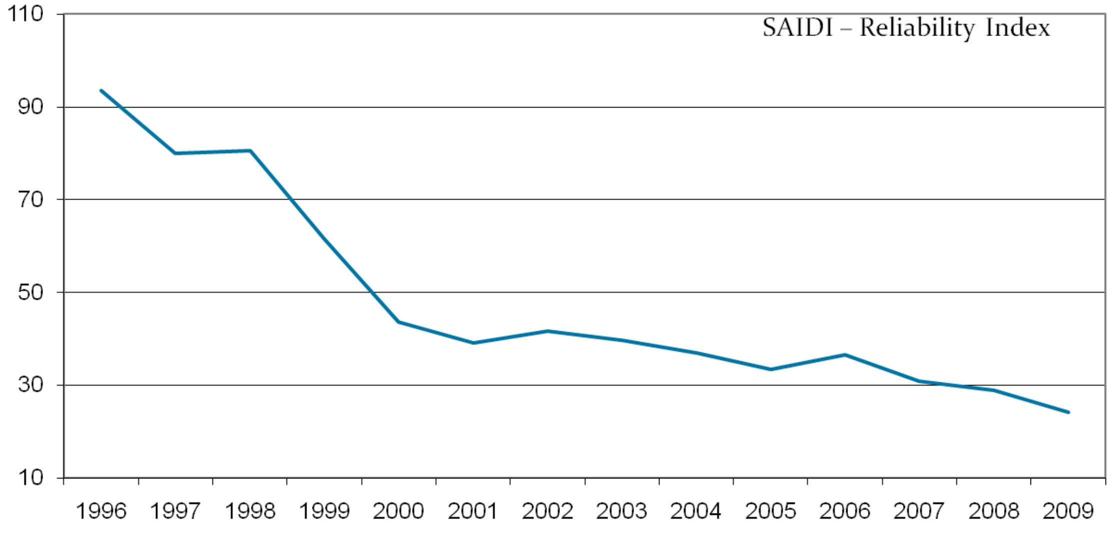
Table 19 shows the current status of Naperville's smart grid program and Figure 1 shows Naperville's SAIDI since 1996. As this data shows, dramatic improvements were made and were accomplished by applying continuous improvement methods to establish a new, more reliable design philosophy (i.e., underground, redundancy and sectionalizing switches). In this process, Naperville applied metrics, set goals, monitored performance and identified the root causes of problems, continuously improving performance through refinements that mitigated the problems as they emerged.

Table 18: Naperville Smart Grid Process

SMART GRID SUBSYSTEM	PERCENT COMPLETE
SCADA	100%
Looping	80%
Underground	>90%
Distribution automation	75%
Substation automation	70%
AMI	two pilot projects just started
Communication infrastructure	70%

Source: Galvin Electricity Initiative. (2010, April). *Naperville Case Study.* http://www.galvinpower.org/galvin-conducts-naperville-smart-grid-initiative-case-study

Figure 1: Naperville SAIDI Improvements



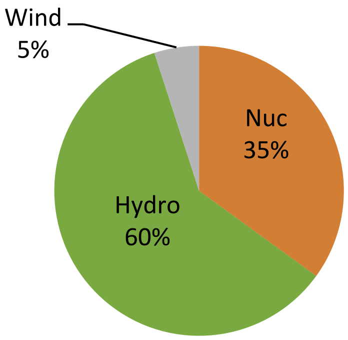
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Average No. Customers	41,714	43,905	46,160	48,214	50,251	51,525	52,825	54,149	54,844	55,551	56,086	56,432	56,747	56,789
SAIDI - Index (Minutes)	93.60	80.00	80.60	61.60	43.60	39.22	41.73	39.76	36.88	33.45	36.54	30.88	28.94	24.24

Source: Galvin Electricity Initiative. (2010, April). *Naperville Case Study.* http://galvinpower.org/galvin-conducts-naperville-smart-grid-initiative-case-study

Appendix B: Zero Direct Carbon Emissions on the IIT Campus

In 1996, Bob Galvin challenged the Illinois Institute of Technology (IIT) to strive for perfection in the delivery of their campus-wide electricity. This included competitive prices, no power failures and no carbon emissions. IIT's initial reaction was simple and direct: The task was impossible. Yet, a mere four years later, IIT was delivering electricity to everyone on site with no direct carbon emissions. This was accomplished through a competitive and innovative electricity supply solicitation. Exelon Energy was selected based on a competitive three-year contract that specifically called for no carbon electricity. Exelon energy delivered with a fuel mix of 60 percent hydro, 35 percent nuclear and 5 percent wind power (see Figure 3). This clean, "no direct carbon" power is being delivered for roughly 25 percent less than the cost of default power in Illinois.

Figure 2: IIT Fuel Mix



How did IIT achieve this success? First, they recognized that a flatter load profile would result in lower prices, and second, they had the ability to aggregate all of their customers for the purpose of procuring power from a third party electricity supplier. This allowed IIT to pursue power from a wide range of suppliers, some of which have quietly built up large fleets of clean power generation (e.g., Exelon Energy).

At the National Association of Regulatory Utility Commissioners' National Electricity Forum held in February 2011, industry leaders revealed that dramatic reductions in carbon delivery are achievable immediately, if consumers have a choice.

- Mary Healey, Connecticut consumer advocate, explained that the state is moving away from renewable portfolio standards and utility-directed efficiency programs because these are too expensive for consumers and ineffective to rationalize the cost. Instead, Connecticut can achieve clean energy goals cost-effectively through competitive markets and state-led competitive clean energy contracts.
- Steve Whitley, president and CEO of the New York Independent System Operator (NYISO), explained that competitive markets are an effective approach to a clean energy future, attracting billions of dollars in investment to New England and New York for 28,000 MW of combined cycle gas generation, as well as significant new wind resources.
- Jack Fusco, president and CEO of Calpine, challenged the state regulators to give their residents access to the 2.5c/kWh marginal cost, clean natural gas power that his company generates nationwide. Most of this clean power produces about 75 percent less carbon than a coal plant.

Appendix C: Waste Calculations

BUILDING INEFFICIENCY

BUILDING INEFFICIENCY WASTE CALCULATIONS			
Sector	Electricity Sales (billion kWh)[46]	End-use Price (cents per kWh)[47]	Cost of 50 percent waste
Residential	1,380	11.4	.50 * $0.114/kWh * 1,380,000,000,000 kWh = $78,660,000,000
Commercial	1,350	10.4	.50 * $0.104/kWh * 1,350,000,000,000 kWh = $70,200,000,000
Total Waste			**$148,860,000,000**

RECOVERABLE WASTE CALCULATIONS			
Lawrence Berkeley National Laboratory estimated that building owners could save up to 30 percent through conservation.[48]			
Sector	Electricity Sales (billion kWh)[49]	End-Use Price (cents per kWh)[50]	Savings from 30 percent improvement
Residential	1,380	11.4	.30 * $0.114/kWh * 1,380,000,000,000 kWh = $47,196,000,000
Commercial	1,350	10.4	.30 * $0.104/kWh * 1,350,000,000,000 kWh = $42,120,000,000
Total Waste			**$89,316,000,000**

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[46] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A8.

[47] Ibid.

[48] Brown, R., Borgeson, S., Koomey, J., & Biermayer, P. (2008). *U.S. Building-Sector Energy Efficiency Potential, LBNL-1096E.* Berkeley: Ernest Orlando Lawrence Berkeley National Laboratory.

[49] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A8.

[50] Ibid.

WASTED CAPITAL

<table>
<tr><th colspan="2">PLANT UTILIZATION CALCULATIONS</th></tr>
<tr><td colspan="2">According to the EIA,[51] the total U.S. generation capacity is 1,010 GW.[52] Total electricity consumption is about 3,800 million MWh. This equates to an average plant utilization of about 40 percent or 400 GW.</td></tr>
<tr><td>System capacity</td><td>1,010,000 MWh</td></tr>
<tr><td>Total system delivered</td><td>3,800,000,000 MWh</td></tr>
<tr><td>System capacity factor</td><td>3,800,000,000 MWh / (1,010,000 MW * 8760) hours = .43</td></tr>
</table>

<table>
<tr><th colspan="2">WASTED GENERATION CAPITAL CALCULATIONS</th></tr>
<tr><td colspan="2">The system capacity calculation above shows that literally more than 50 percent of our installed generation is wasted. At $2,200/kW[53], this waste is costing consumers $37 billion a year.</td></tr>
<tr><td>Wasted generation</td><td>.50 * 1,010,000 MWh = 505,000 MWh = 505,000,000 kWh</td></tr>
<tr><td>Plant costs</td><td>$2,200/KW</td></tr>
<tr><td>Term</td><td>30 years</td></tr>
<tr><td>Total costs</td><td>$2,200/kWh * 505,000,000 kWh = 1,111,000,000,000</td></tr>
<tr><td>Annual costs</td><td>$1,111,000,000,000 / 30 years = $37,033,333,333/yr</td></tr>
</table>

<table>
<tr><th colspan="2">WASTED DISTRIBUTION CAPITAL CALCULATIONS</th></tr>
<tr><td colspan="2">The very peaky load causes enormous waste in our T&D system as well. At $1,500/kW[54], this waste is costing consumers $25 billion a year.</td></tr>
<tr><td>Wasted generation</td><td>.50 * 1,010,000 MWh = 505,000 MWh = 505,000,000 kWh</td></tr>
<tr><td>Plant costs</td><td>$1,500/KW</td></tr>
<tr><td>Term</td><td>30 years</td></tr>
<tr><td>Total costs</td><td>$1,500/kWh * 505,000,000 kWh = $757,500,000,000</td></tr>
<tr><td>Annual costs</td><td>$757,500,000,000 / 30 years = $25,250,000,000/yr</td></tr>
</table>

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[51] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* p. 66–67.

[52] U.S. Energy Information Administration, U.S. Department of Energy. (2008). *Existing Generating Units in the United States by State, Company and Plant 2008.* Retrieved from http://www.eia.doe.gov/cneaf/electricity/page/capacity/capacity.html

[53] Assumed average cost of generation per kilowatt hour.

[54] Assumed average cost of transmission and distribution per kilowatt hour.

<table>
<tr><th colspan="2">AVOIDABLE GENERATION CAPITAL CALCULATIONS</th></tr>
<tr><td colspan="2">The EIA <i>Annual Energy Outlook</i> Table A9 projects that the U.S. will add about 170 GW. Assuming that 100 GW of generation is unneeded equates to annual waste of $8 billion at $2,200/KW[55] financed over 30 years.</td></tr>
<tr><td>Projected new generation</td><td>100 GW = 100,000,000 kW</td></tr>
<tr><td>Plant costs</td><td>$2,200/KW</td></tr>
<tr><td>Interest rate</td><td>5 percent</td></tr>
<tr><td>Term</td><td>30 years</td></tr>
<tr><td>Total costs</td><td>$2200/kW * 100,000,000 kW = $220,000,000,000</td></tr>
<tr><td>Annual waste</td><td>.05 * $220,000,000,000 * (1+.05)^30 / ((1+.05)^30-1) = $14,311,315,718</td></tr>
</table>

<table>
<tr><th colspan="2">AVOIDABLE DISTRIBUTION CAPITAL CALCULATIONS</th></tr>
<tr><td colspan="2">The Brattle Group estimates that $1.5 to $2 trillion needs to be spent on the U.S. utility distribution infrastructure expansion over the next 20 years to meet the projected demand growth.[56] However, grid modernization will actually enable consumers to reduce their electricity consumption. Assuming that at least 10 percent of this investment is unnecessary equates to an annual waste of $10 billion financed over 30 years.</td></tr>
<tr><td>Avoided distribution infrastructure investment</td><td>$150,000,000,000</td></tr>
<tr><td>Interest rate</td><td>5 percent</td></tr>
<tr><td>Term</td><td>30 years</td></tr>
<tr><td>Annual waste</td><td>.05 * $150,000,000,000 * (1+.05)^30 / ((1+.05)^30-1) = $9,757,715,262</td></tr>
</table>

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[55] Assumed average cost of generation per kilowatt hour.

[56] Chupta, M., Earle, R., Fox-Penner, P., & Hledik, R. (2008). *Transforming America's Power Industry: The Investment Challenge 2010-2030.* The Brattle Group. The Brattle Group also estimates that 214 GW of new generation will be required by 2030 at a cost of $697 billion. This works out to a cost of $3,257 per installed kilowatt.

GENERATION AND DISTRIBUTION ENERGY INEFFICIENCY

ELECTRICITY SUPPLIED CALCULATIONS

The annual electricity sales for each sector can be found in the *Annual Energy Outlook 2010*, Table A8: Electricity Supply, Disposition, Prices and Emissions.

Sector	Sales (million MWh)[57]	Sales (mmBTU)[58]	Sales (QBTU)[59]
Residential	1,380	4,709,940,000	4.71
Commercial	1,350	4,607,550,000	4.61
Industrial	980	3,344,740,000	3.34
Total	**3710**	**12,662,230,000**	**12.66**

GENERATION AND DISTRIBUTION EFFICIENCY CALCULATIONS

The total fossil fuel consumption can be found in the *Annual Energy Outlook 2010*, Table A2. We find that 36.6 QBTU of electricity is consumed while only 12.66 QBTU actually reaches end-users. This reveals an electric system efficiency of 35 percent.

Total fossil fuel consumption for electricity	36.6 QBTU[60]
Electricity supplied	12.66 QBTU
Electricity system efficiency = (12.66 QBTU/36.6 QBTU)*100	**35 percent**

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[57] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A8.

[58] 1MWh = 3.413 mm BTU.

[59] 1mmBTU = 1 billion QBTU.

[60] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A2.

GENERATION AND DISTRIBUTION EFFICIENCY WASTE CALCULATIONS

When generating and transmitting electricity, thermal losses are inevitable. The farther power is sent, the more energy is lost. This equates to about 24 quadrillion BTU or $70 billion annually in wasted fuel.

Sector	100% Efficiency	Baseline Efficiency 35% (Sales mmBTU/.35)	Waste at $3/mmBTU
Residential	4,709,940,000	13,456,971,428	$3/mmBTU * (13,456,971,428 mmBTU - 4,709,940,000 mmBTU) = $26,241,094,284
Commercial	4,607,550,000	13,164,428,571	$3/mmBTU * (13,164,428,571 mmBTU - 4,607,550,000 mmBTU) = $25,670,635,713
Industrial	3,344,740,000	9,556,400,000	$3/mmBTU * (9,575,902,857 mmBTU - 3,351,566,000 mmBTU) = $18,634,980,000
Total	**$70,546,709,997**		

RECOVERABLE WASTE CALCULATIONS

It is assumed that new smart grid rules that allow customers the choice to procure generation with higher efficiencies and vertically integrated utility commissions that pursue competitive higher efficiency generation will produce a 50 percent improvement in generation efficiency, creating a new system efficiency of 53 percent. Savings are achieved when less fuel is consumed to supply the same electricity requirements.

Sector	Baseline Efficiency 35% (Sales mmBTU/.34)	Improved Efficiency 53% (Sales mmBTU/.53)	Savings at $3/mmBTU
Residential	13,456,971,428	8,886,679,245	$3/mmBTU * (3,456,971,428 mmBTU - 8,886,679,245 mmBTU) = $13,710,876,549
Commercial	13,164,428,571	8,693,490,566	$3/mmBTU * (13,164,428,571 mmBTU - 8,693,490,566 mmBTU) = $13,412,814,015
Industrial	9,556,400,000	6,310,830,188	$3/mmBTU * (9,556,400,000 mmBTU - 6,310,830,188 mmBTU) = $9,736,709,436
Total	**$36,860,400,000**		

POOR POWER RELIABILITY AND QUALITY

RELIABILITY AND POWER QUALITY WASTE CALCULATIONS	
LBNL estimated the economic losses of unreliable electricity to be approximately $80 billion per year, but it could be as high as $130 billion per year, not including power quality events.[61] Reports by the Electric Power Research Institute and the U.S. Department of Energy have estimated the cost of electricity outages at $30 billion to $400 billion per year.[62]	
Estimated annual national cost of outages to consumers and businesses, based on the figures above	**$150,000,000,000**

RECOVERABLE WASTE CALCULATIONS	
Based on the assumption that smart grid investments will improve reliability and power quality performance by 50 percent, we estimate a $75 billion in indirect savings for consumers.	
Recoverable waste from grid improvements	.5 * $150,000,000,000 = **$75,000,000,000**

EMISSIONS WASTE COST

EMISSIONS WASTE CALCULATIONS			
The *Annual Energy Outlook*[63] summarizes major emissions from electricity generation as 2.4 billion tons of carbon dioxide (Table A18), 7 million tons of sulfur dioxide (page 82) and 3 million tons of nitrogen oxide (page 82) at costs estimated at $20 (assumed), $1,500 (page 82) and $3,000 (page 82) per ton over the next decade, respectively. The total annual cost is estimated at $68 billion.			
Emission Type	**Emission amount (tons)**	**Emission cost per ton**	**Emission cost total**
Carbon Dioxide	2,400,000,000	$20	2,400,000,000 tons * $20 / ton = $48,000,000,000
Sulfur Dioxide	7,000,000	$1,500	7,000,000 tons * $1,500 / ton = $10,500,000,000
Nitrogen Oxide	3,000,000	$3,000	3,000,000 tons * $3,000 / ton = $9,000,000,000
Total			**$67,500,000,000**

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[61] LaCammare, K. H., & Eto, J. H. (2004). *Understanding the Cost of Power Interruptions to U.S. Electricity Consumers, LBNL 55718.* Ernest Orlando Lawrence Berkeley National Laboratory, Energy Analysis. Berkeley: University of California Berkeley.

[62] Primen. (2001). *The Cost of Power Disturbances to Industrial and Digital Economy Companies.* Consortium for Electric Infrastructure to Support a Digital Society. Madison: EPRI.

[63] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Tables A1 – A20.

RECOVERABLE WASTE CALCULATIONS			
The savings shown below assume a , percent reduction in emissions based on improvements in conservation, generation efficiency and reductions in generation emissions.			
Emission Type	**30% reduction in emissions (tons)**	**Emission cost per ton**	**Reduced emission cost total**
Carbon Dioxide	.30 * 2,400,000,000 = 720,000,000	$20	720,000,000 tons * $20/ton = $14,400,000,000
Sulfur Dioxide	.30 * 7,000,000 = 2,100,000	$1500	2,100,000 tons * $1500/ton = $3,150,000,000
Nitrogen Oxide	.30 * 3,000,000 = 900,000	$3000	900,000 tons * $3000/ton = $2,700,000,000
Total			**$20,250,000,000**

Appendix D: Benefit Calculations

ELECTRICITY CONSUMPTION SAVINGS

CONSUMPTION BASELINE CALCULATIONS	
Total residential consumption	1,380,000,000,000 kWh[64]
Total number of residential customers	125,000,000[65]
Annual average consumption per customer	1,380,000,000,000 kWh / 125,000,000 = 11,040 kWh
Average national price	$0.114/kWh[66]
Average annual residential bill	$0.114 * 11,040 kWh = $1,259

CONSUMPTION SAVINGS CALCULATIONS	
Because definitive data has not been found that analyzes the permanence of energy savings over an extended period of time from home automation, this research paper makes the conservative assumption of 10 percent savings based on information from several automation companies.	
Supporting Data **Vantage**[67] claims that in the average home, 40 percent of all electricity used to power home electronics is consumed while they are turned off, and dimming all or most of your lights just 25 percent saves 5 percent in overall energy consumption. **Cortexa**[68] claims their automation products can save homeowners 30 percent on their energy bills. **Magnum Energy Solutions**[69] conducted a study at a Wyndham Hotel that shows that rooms using their Venergy automation system consumed 33 percent less energy than rooms without these controls. **Lutron**[70] reported 40 to 60 percent reductions to lighting loads in the commercial sector, without adversely affecting productivity.	
10 percent reduction in electricity consumption	.10 * 11,040 kWh = 1,104 kWh
Consumption savings per customer	1,104 kWh * $0.114/kWh = **$125.86**

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[64] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A8.

[65] U.S. Energy Information Administration, U.S. Department of Energy. (2010). Table 5. Residential Average Monthly Bill by Census Division, and State. Retrieved from http://www.eia.doe.gov/cneaf/electricity/esr/table5.html

[66] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Tables A1 – A20.

[67] Vantage. (2011). *Home Automation Savings.* Retrieved from http://www.vantagecontrols.com/green/home_automation_savings.html

[68] Cortexa Automation. (2011). *Cortexa Energy Saving Edition.* Retrieved from http://www.cortexa.com/EnergyEdition

[69] Magnum Energy Solutions. (2009, October 21). *Independent Study: En-Ocean-Based Verde Controls Reduce Hotel Room Energy Consumption 33%.* Retrieved from http://www.magnumenergysolutions.com/case-study.php

[70] Lutron. (2011). *Commercial Solutions: Energy Savings*. Retrieved from http://www.lutron.com/Residential-Commercial-Solutions/Commercial-Solutions/Pages/CommercialEnergySavings.aspx

DYNAMIC PRICING, TIME OF USE, SHIFTING PEAK DEMAND

DYNAMIC PRICING, TIME OF USE, SHIFTING PEAK DEMAND SAVINGS CALCULATIONS	
The Pacific Northwest National Laboratory (PNNL) reported peak load reductions of 20 percent in the Olympia Peninsula demonstration project using dynamic pricing rate structures.[71] An analysis for Illinois Institute of Technology (IIT) indicated that IIT could save 25 percent of their electric costs just by switching to real-time from fixed-price, third-party rates based on their 2006 electricity procurement contract, 2006 real-time rates from PJM in ComEd's territory and IIT's 2006 hourly electricity consumption. Based on a conservative 10 percent reduction of electric costs, the average household will save $113.	
Reduced annual residential consumption	11,040 kWh – 1,104 kWh = 9,936 kWh
10 percent reduction in costs	.10 * $.114/kWh * 9,936 kWh = **$113**

AVOIDED NEW GENERATION COSTS

GENERATION CAPACITY	
If, through grid modernization, consumers could permanently reduce their peak demand by 10 percent, the U.S. peak demand could be reduced by about 100 GW.[72] This would more than offset the projected 100 GW of new demand by 2025. Furthermore, in a restructured generation market, the private sector bears the cost of capital for new generation.	
Current generation	1,010 GW[73]
Projected new generation	**100 GW**[74]

AVOIDED GENERATION CAPACITY COSTS	
Assuming a new power plant costs 2,200/kW and financing costs about 5 percent over 30 years, avoided capacity costs are achieved at a rate of $.004/kWh.	
Avoided capacity	100,000,000 kW
New plant cost	$2,200/kW[75]

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[71] Hammerstrom, D., Ambrosio, R., Brous, J., Carlon, T., Chassin, D., DeSteese, J., et al. (2007). *Pacific Northwest GridWise Testbed Demonstrations Projects: Part I. Olympia Peninsula Project, PNNL-17167.* Richland: Pacific Northwest National Laboratory.

[72] This estimate assumes that the residential portion of peak capacity is proportional to the ratio of residential consumption over total U.S. consumption. Total U.S. consumption was assumed to be 3,764 GWh and residential consumption was assumed to be 1,392 GWh based on U.S. Department of Energy, U.S. Energy Information Administration, Table 5.1. Retail Sales of Electricity to Ultimate Customers: Total by End-Use Sector, 1996 through August 2010, http://www.eia.doe.gov/fuelelectric.html.

[73] U.S. Energy Information Administration, U.S. Department of Energy. (2008). *Existing Generating Units in the United States by State, Company and Plant 2008.* Retrieved from http://www.eia.doe.gov/cneaf/electricity/page/capacity/capacity.html

[74] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A9.

[75] Assumed average cost of generation per kilowatt hour.

Interest rate	5 percent
Term	30 years
Total plant cost	$2,200/kW * 100,000,000 kW = $220,000,000,000
Annual plant payment	.05 * $220,000,000,000 * (1+.05)^30 / ((1+.05)^30-1) = $14,311,315,718
Avoided generation capacity costs per kWh	$14,311,315,718 / 3,710,000,000,000 kWh[76] = **$.004/kWh**

<table>
<tr><th colspan="3">SAVINGS PER HOUSEHOLD</th></tr>
<tr><td colspan="3">These avoided generation capacity costs result in savings of more than $50 per average U.S. household. This assumes that 50 percent of the commercial and industrial savings are passed on to consumers.</td></tr>
<tr><th>Sector</th><th>Consumption (kWh)</th><th>Savings passed on to households</th></tr>
<tr><td>Residential</td><td>1,380,000,000,000[77]</td><td>1,380,000,000,000 kWh * $.004/kWh = $5,520,000,000</td></tr>
<tr><td>Commercial</td><td>1,350,000,000,000[78]</td><td>.5 * 1,350,000,000,000 * $.004/kWh = $2,700,000,000</td></tr>
<tr><td>Industrial</td><td>980,000,000,000[79]</td><td>.5 * 980,000,000,000 * $.004/kWh = $1,960,000,000</td></tr>
<tr><td>Total savings</td><td colspan="2">$10,180,000,000</td></tr>
<tr><td>Total savings per household</td><td colspan="2">$10,180,000,000 / 125,000,000 customers[80] = $81.44</td></tr>
</table>

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[76] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A8.

[77] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A8.

[78] Ibid.

[79] Ibid.

[80] U.S. Energy Information Administration, U.S. Department of Energy. (2010, November). Table 5. Residential Average Monthly Bill by Census Division, and State. Retrieved from http://www.eia.doe.gov/cneaf/electricity/esr/table5.html

AVOIDED NEW DISTRIBUTION COSTS

AVOIDED NEW DISTRIBUTION CAPACITY COSTS	
The Brattle Group estimates that $1.5 to $2 trillion needs to be spent on the U.S. utility distribution infrastructure expansion over the next 20 years to meet the projected demand growth.[81] Assuming that 10 percent of this investment can be avoided, infrastructure capacity costs are avoided at a rate of $.0079/kWh.	
Total infrastructure improvement costs	$1,500,000,000,000
Avoided cost	.10 * $1,500,000,000,000 = $150,000,000,000
Interest rate	5 percent
Term	30 years
Annual payment	.05 * $150,000,000,000 * (1+.05)^30 / ((1+.05)^30-1) = $9,757,715,262
Avoided infrastructure capacity costs per kWh	$9,757,715,262 / 3,710,000,000,000 kWh[82] = **$.0026/kWh**

SAVINGS PER HOUSEHOLD		
This calculation assumes that 50 percent of the commercial and industrial savings are passed on to consumers.		
Sector	**Consumption (kWh)**	**Savings passed on to households**
Residential	1,380,000,000,000[83]	1,380,000,000,000 kWh * $.0026/kWh = $3,588,000,000
Commercial	1,350,000,000,000[84]	.5 * 1,350,000,000,000 * $.0026/kWh = $1,755,000,000
Industrial	980,000,000,000[84]	.5 * 980,000,000,000 * $.0026/kWh = $1,274,000,000
Total savings	$6,617,000,000	
Total savings per household	$6,617,000,000 / 125,000,000 customers[85] = **$53**	

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[81] Chupta, M., Earle, R., Fox-Penner, P., & Hledik, R. (2008). *Transforming America's Power Industry: The Investment Challenge 2010-2030.* The Brattle Group. Note that the Brattle Group also estimates that 214 GW of new generation will be required by 2030 at a cost of $697 billion. This works out to a cost of $3,257 per installed kilowatt.

[82] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A8.

[83] Ibid.

[84] Ibid.

[85] U.S. Energy Information Administration, U.S. Department of Energy. (2010). Table 5. Residential Average Monthly Bill by Census Division, and State. Retrieved from http://www.eia.doe.gov/cneaf/electricity/esr/table5.html

GENERATION INEFFICIENCIES

ELECTRICITY SUPPLIED CALCULATIONS

The annual electricity sales for each sector can be found in *Annual Energy Outlook 2010*, Table A8: Electricity Supply, Disposition, Prices and Emissions.

Sector	Sales (million MWh)[86]	Sales (mmBTU)[87]	Sales (QBTU)[88]
Residential	1,380	4,709,940,000	4.71
Commercial	1,350	4,607,550,000	4.61
Industrial	980	3,344,740,000	3.34
Total	**3710**	**12,662,230,000**	**12.66**

GENERATION AND DISTRIBUTION EFFICIENCY CALCULATIONS

The total fossil fuel consumption can be found in the *Annual Energy Outlook 2010*, Table A2. We find that 36.6 QBTU of electricity is consumed while only 12.66 QBTU actually reaches end-users. This reveals an electric system efficiency of 35 percent.

Total fossil fuel consumption for electricity	36.6 QBTU[89]
Electricity supplied	12.66 QBTU
Electricity system efficiency = (12.66 QBTU / 36.6 QBTU) * 100	**35 percent**

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[86] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A8.

[87] 1MWh = 3.413 mmBTU.

[88] 1mmBTU = 1 billion QBTU.

[89] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A2.

<table>
<tr><th colspan="4">TOTAL GENERATION EFFICIENCY SAVINGS CALCULATIONS</th></tr>
<tr><td colspan="4">It is assumed that new smart grid rules that allow customers the choice to procure generation with higher efficiencies and vertically integrated utility commissions that pursue competitive higher efficiency generation will produce a 50 percent improvement in generation efficiency, creating a new system efficiency of 53 percent. Savings are achieved when less fuel is consumed to supply the same electricity requirements.</td></tr>
<tr><th>Sector</th><th>Baseline efficiency 35% (Sales mmBTU/.34)</th><th>Improved efficiency 53% (Sales mmBTU/.44)</th><th>Savings at $3/mmBTU</th></tr>
<tr><td>Residential</td><td>13,456,971,428</td><td>8,886,679,245</td><td>$3/mmBTU * (3,456,971,428 mmBTU - 8,886,679,245 mmBTU) = $13,710,876,549</td></tr>
<tr><td>Commercial</td><td>13,164,428,571</td><td>8,693,490,566</td><td>$3/mmBTU * (13,164,428,571 mmBTU - 8,693,490,566 mmBTU) = $13,412,814,015</td></tr>
<tr><td>Industrial</td><td>9,556,400,000</td><td>6,310,830,188</td><td>$3/mmBTU * (9,556,400,000 mmBTU - 6,310,830,188 mmBTU) = $9,736,709,436</td></tr>
<tr><td>Total</td><td colspan="3">$36,860,400,000</td></tr>
</table>

<table>
<tr><th colspan="2">SAVINGS PER HOUSEHOLD CALCULATIONS</th></tr>
<tr><td colspan="2">This calculation assumes that 50 percent of the commercial and industrial savings are passed on to consumers.</td></tr>
<tr><th>Sector</th><th>Savings passed on to households</th></tr>
<tr><td>Residential</td><td>$13,710,876,549</td></tr>
<tr><td>Commercial</td><td>.5 * $13,412,814,015 = $6,706,407,008</td></tr>
<tr><td>Industrial</td><td>.5 * $9,736,709,436 = $4,868,354,718</td></tr>
<tr><td></td><td>$25,285,638,275</td></tr>
<tr><td>Total savings per household</td><td>$25,285,638,275 / 125,000,000 customers[90] = $202</td></tr>
</table>

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[90] U.S. Energy Information Administration, U.S. Department of Energy. (2010, November). Table 5: Residential Average Monthly Bill by Census Division, and State. Retrieved from http://www.eia.doe.gov/cneaf/electricity/esr/table5.html

REDUCED TRANSMISSION AND DISTRIBUTION (T&D) LOSSES

AVERAGE T&D COSTS CALCULATIONS

The current costs of transmission and distribution are included in Table A8 of EIA's *Annual Energy Outlook 2010*.

Service category	Price per KWh[91]	Price per MWh[92]
Transmission	$0.007	$7.00
Distribution	$0.024	$24.00
Total	**$0.031**	**$31.00**

GENERATION COSTS CALCULATIONS

The cost of generation per sector is determined by subtracting the T&D cost from the retail price of electricity.

Sector	Retail price per MWh[93]	Generation cost per MWh
Residential	$112.60	$112.60 - $31.00 = $81.60
Commercial	$103.60	$103.60 - $31.00 = $72.60
Industrial	$68.30	$68.30 - $31.00 = $37.3

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[91] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A8.

[92] 1MWh = 1,000 kWh.

[93] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Retail Sales of Electricity to Ultimate Customers: Total by End-Use Sector.* Retrieved from http://www.eia.doe.gov/cneaf/electricity/epm/table5_1.html

SAVINGS FROM REDUCED T&D LOSSES CALCULATIONS		
The EIA estimates that investment in grid modernization will cause a 1.6 percent improvement in transmission and distribution losses. This translates to reduction in generation costs to consumers.[94]		
Sector	**Sales (million MWh)[95]**	**Savings from reduced T&D losses per sector**
Residential	1,380	.016 * $81.60 / MWh * 1,380,000,000 MWh = $1,801,728,000
Commercial	1,350	.016 * $72.60 / MWh * 1,350,000,000 MWh = $1,568,160,000
Industrial	980	.016 * $37.30 / MWh * 980,000,000 MWh = $584,864,000

SAVINGS PER HOUSEHOLD CALCULATIONS	
The savings per household is determined by dividing the total savings by the number of residential consumers. We are assuming that only 50 percent of commercial and industrial savings will be passed on to residential consumers.	
Sector	**Savings passed on to households**
Residential	$1,801,728,000
Commercial	.5 * $1,568,160,000 = $784,080,000
Industrial	.5 * $584,864,000 = $292,432,000
	$2,878,240,000
Total savings per household	$2,878,240,000 / 125,000,000 customers[96] = **$23.03**

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[94] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* p.10.

[95] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A8.

[96] U.S. Energy Information Administration, U.S. Department of Energy. (2010, November). Table 5: Residential Average Monthly Bill by Census Division, and State. Retrieved from http://www.eia.doe.gov/cneaf/electricity/esr/table5.html

RELIABILITY AND POWER QUALITY

RELIABILITY AND POWER QUALITY COST CALCULATIONS	
LBNL estimated the economic losses of unreliable electricity to be approximately \$80 billion per year, but it could be as high as \$130 billion per year, not including power quality events.[97] Reports by the Electric Power Research Institute and the Department of Energy have estimated the cost of electricity outages at \$30 billion to \$400 billion per year.[98]	
Estimate of annual national cost of outages to consumers and businesses, based on the figures above	**\$150,000,000,000**

RELIABILITY AND POWER QUALITY SAVINGS CALCULATIONS	
Based on the assumption that smart grid investments will improve reliability and power quality performance by 50 percent, \$75 billion is estimated in indirect savings for consumers.	
Recoverable waste from grid improvements	.5 x \$150,000,000,000 = **\$75,000,000,000**

RELIABILITY AND POWER QUALITY SAVINGS CALCULATIONS			
Assuming 50 percent of the commercial and industrial costs gets passed on to consumers, this works out to an average household cost of outages of \$410 per year.			
Sector	**Sales (million MWh)[99]**	**Outage cost savings per sector**	**Savings per household**
Residential	1,380	\$27,000,000,000	\$27,000,000,000 / 125,000,000 customers = \$216
Commercial	1,350	\$27,000,000,000	.5 *\$27,000,000,000 / 125,000,000 customers = \$108
Industrial	980	\$21,000,000,000	.5 * \$21,000,000,000 / 125,000,000 customers = \$84
Total	**3,710**	**\$75,000,000,000**	**\$408**

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[97] LaCammare, K. H., & Eto, J. H. (2004). *Understanding the Cost of Power Interruptions to U.S. Electricity Consumers, LBNL 55718.* Ernest Orlando Lawrence Berkeley National Laboratory, Energy Analysis. Berkeley: University of California Berkeley.

[98] Primen. (2001). *The Cost of Power Disturbances to Industrial and Digital Economy Companies.*Consortium for Electric Infrastructure to Support a Digital Society. Madison: EPRI.

[99] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A8.

EMISSION REDUCTION CREDITS

ANNUAL COST OF MAJOR EMISSIONS CALCULATIONS			
The *Annual Energy Outlook*[100] summarizes major emissions from electricity generation as 2.4 billion tons of carbon dioxide (Table A18), 7 million tons of sulfur dioxide (page 82) and 3 million tons of nitrogen oxide (page 82) at costs estimated at $20 (assumed), $1,500 (page 82), and $3,000 (page 82) per ton over the next decade, respectively. The total annual cost is estimated at $68 billion.			
Emission type	**Emission amount (tons)**	**Emission cost per ton**	**Emission cost total**
Carbon Dioxide	2,400,000,000	$20	2,400,000,000 tons * $20 / ton = $48,000,000,000
Sulfur Dioxide	7,000,000	$1,500	7,000,000 tons * $1500 / ton = $10,500,000,000
Nitrogen Oxide	3,000,000	$3,000	3,000,000 tons * $3,000 / ton = $9,000,000,000
Total			**$67,500,000,000**

EMISSIONS SAVINGS CALCULATIONS	
The savings shown below assume a 30 percent reduction in emissions based on improvements in conservation, generation efficiency and reductions in generation emissions.	
Recoverable waste from grid improvements	.3 * $67,500,000,000 / 3710 million MWh[101] = $5.45/MWh

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[100] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Tables A1 – A20.

[101] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A8.

EMISSIONS SAVINGS CALCULATIONS

The savings shown below assume a 30 percent reduction in emissions based on improvements in conservation, generation efficiency and reductions in generation emissions.

Sector	Sales (million MWh)[102]	Outage cost savings per sector	Savings per household
Residential	1,380	$5.45 * 1,380,000,000 = $7,521,000,000	$7,515,550,000 / 125,000,000 customers = $60
Commercial	1,350	$5.45 * 1,350,000,000 = $7,357,500,000	.5 *$7,368,400,000 / 125,000,000 customers = $29
Industrial	980	$5.45 * 980,000,000 = $5,341,000,000	.5 * $5,351,900,000 / 125,000,000 customers = $21
Total			**$110**

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[102] U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010,* Table A8.