Smart Grid Economic and Environmental Benefits

A Review and Synthesis of Research on Smart Grid Benefits and Costs

SmartGrid consumer collaborative

October 8, 2013

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About This Review

Many researchers have forecast the likely costs and benefits of a Smart Grid using macroeconomic analysis. In 2011 the Electric Power Research Institute forecast that the cost to upgrade the U.S. grid to "smart" status would be between $338 billion and $476 billion, and would generate benefits of between $1,294 billion and $2,028 billion,[1] for an anticipated benefit-to-cost ratio of between 2.8 and 6.0 to 1. U.S. utility Smart Grid business cases typically forecast benefit-to-cost ratios of between 1.1 and 3.0 to 1.

Because real-world experience with the Smart Grid is growing, the Smart Grid Consumer Collaborative (SGCC) completed a review of available research quantifying the actual – rather than forecast – benefits and costs to help stakeholders analyze and maximize the value of various capabilities. This report summarizes available research in terms consumers can understand and synthesizes findings in a "per customer" context whenever possible.

Smart Grid planning and investment is undertaken in a complex environment with numerous stakeholders, including, among others:

- Consumer advocates
- Environmental advocates
- Regulators
- Consumers
- Legislators
- Utilities
- Hardware, software, and service suppliers to the utility industry

This review aims to help these stakeholders determine what U.S. consumers can realistically expect to receive relative to Smart Grid investment for their money based on demonstrated experience. It has been specifically developed to help stakeholders understand:

- Exactly how Smart Grid capabilities create value relative to a traditional grid
- The size of the various benefits (economic, reliability, environmental, and customer choice) as supported by available research, expressed "per customer per year" whenever possible
- The key drivers of these benefits
- The costs typically incurred to create those benefits, expressed "per customer" whenever possible

1 Electric Power Research Institute, 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, March 2011, 1–4.

"Technical and Economic Concepts Related to the Smart Grid – A Guide for Consumers"

We have created "Technical and Economic Concepts Related to the Smart Grid – A Guide for Consumers," a separate guide detailing certain technical and economic concepts discussed in this review. The guide is available from the SGCC, and we encourage readers interested in additional details to consult the guide.

About the Smart Grid Consumer Collaborative

SGCC is a consumer-focused nonprofit organization formed to promote an understanding of the benefits of modernized electrical systems among all stakeholders in the United States. Membership is open to all consumer and environmental advocates, technology vendors, research scientists, and electric utilities for sharing research, best practices, and collaborative efforts of the group. Learn more at smartgridcc.org.

About the Wired Group

This research was conducted by the Wired Group, a consultancy helping clients unleash the latent value in distribution utility businesses. Learn more at wiredgroup.net.

Acknowledgements

The SGCC would like to thank the many individuals, companies, and organizations that helped formulate insights from the research reviewed and provided feedback on the content, themes, and layout of this review. Only by continuing to collaborate on consumer issues will we be able to fully realize the promise of Smart Grid. If you are not a member, we invite you to join us as we continue to listen, collaborate, and educate going forward.

October 8, 2013

Patty Durand, Executive Director
Smart Grid Consumer Collaborative

Smart Grid Consumer Collaborative Members

The following organizations support the Smart Grid Consumer Collaborative and its mission:

- Accenture
- ACEEE
- Aclara Technologies
- Alameda Municipal Power
- Alliance to Save Energy
- Ameren Illinois
- Arizona Public Service Company
- Association for Demand Response & Smart Grid
- Avista Utilities
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- Benton PUD
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- California Public Utilities Commission
- CenterPoint Energy
- Climate + Energy Project
- CNT Energy
- Cobb EMC
- Colorado Public Utilities Commission
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- IBM
- Illinois Citizens Utility Board
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- Idaho Falls Power
- Intelligent Energy Solutions LLC
- Itron
- Landis + Gyr
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- Market Strategies International
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- Natural Resources Defense Council
- NC Department of Commerce – Energy Office
- NETL – Smart Grid Implementation Task Force
- New Brunswick Power Corporation
- North Carolina Sustainable Energy Association
- Office of People's Counsel DC
- Office of the Ohio Consumers' Counsel
- Oklahoma Gas & Electric
- Oncor
- Opower
- Oracle
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- Pacific Gas and Electric Company
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- PayGo
- Peak Load Management Alliance
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- Portland General Electric
- Power Systems Consultants, Inc.
- Public Utility Commission of Texas
- Research Triangle Cleantech Cluster
- Sempra Utilities / San Diego Gas & Electric
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- TechAmerica
- Tendril
- Tennessee Valley Authority
- Texas Office of Public Utility Counsel
- Tri-County Electric Cooperative
- TVPPA
- Utility Consumers' Action Network
- Vermont Energy Investment Corporation

1. EXECUTIVE SUMMARY

The SGCC completed this review to help stakeholders better understand the benefits – economic, environmental, reliability, and customer choice – associated with Smart Grid investments. We present controlled studies from actual Smart Grid deployments whenever possible, synthesizing research results into a "per customer per year" context using assumptions based on actual Smart Grid deployments. In order to reflect variability across different utility operating environments, we present a set of conservative assumptions that we refer to as the "Reference Case," along with more aggressive assumptions reflecting "the state of the possible" that we refer to as the "Ideal Case." We also describe the benefit drivers for each Smart Grid capability.

Findings

We believe readers of this report are likely to reach the conclusion that Smart Grid investments offer economic benefits in excess of costs, and likewise offer significant reductions in environmental impact.

Smart Grid Investment Offers Economic Benefits in Excess of Costs

The Smart Grid appears to offer both direct benefits (those which could affect consumers' bills) and indirect economic benefits to customers. Direct benefits are delivered through four primary mechanisms:

- Increasing electric distribution efficiency, primarily through Integrated Volt/VAr Control (IVVC).
- Facilitating changes in customer behavior, either by shifting usage away from high-demand periods or by reducing usage. These capabilities include offering customers more choices including time-varying rates, prepayment programs, and customer energy management systems.
- Reducing operating costs from capabilities such as remote meter reading and remote service disconnect/reconnect.
- Improving revenue capture through improved Smart Meter accuracy and theft detection capabilities.

The Smart Grid also appears to offer significant indirect benefits to communities through economic productivity increases associated with improved grid reliability. Capabilities such as fault location help repair crews find faults faster, while fault isolation limits the number of customers impacted by any particular service outage.

Smart Grid Investment Offers Significant Reductions in Environmental Impact

The Smart Grid offers significant reductions in environmental impact through two sources: conservation and greater renewable generation integration. Greenhouse gas[2] emission reductions can be traced directly to Smart Grid capabilities – such as time-varying rates and customer energy management systems – offering a conservation effect. We find that the Smart Grid increases the level of customer-sited generation that the distribution grid can reliably and efficiently accommodate. To the extent this generation is renewable, Smart Grid capabilities designed to accommodate it offer even more significant environmental benefits.

Direct and Indirect Benefits by Capability per Customer per Year

Reference Case and Ideal Case Benefits

Table 1 summarizes the available benefits from various Smart Grid capabilities found in the research. In many cases, we have made assumptions about key benefit drivers such as customer participation rates to convert the research findings into a "per customer per year" metric. Where a range is presented, the low end represents the Reference Case, which embodies assumptions typical of the current average capability deployment. The high end represents the Ideal Case, which is based on assumptions that, though the research indicates are achievable, may not be reached unless the benefit drivers are carefully and thoughtfully optimized by Smart Grid stakeholders.

Not all Smart Grid capabilities are subject to large variation. For example, capabilities designed to improve reliability are not driven by customer participation rates. In other cases, insufficient research for a particular capability is available on which to base differences between a Reference Case and Ideal Case, rendering any such distinctions arbitrary. A summary of Reference Case and Ideal Case assumptions is presented in the appendices. Sources are footnoted throughout this review.

Direct and Indirect Benefits

Direct benefits are those that could affect customers' bills, whereas the indirect benefit calculations represent our attempt to translate reliability and environmental performance improvements from Smart Grid capabilities into economic terms.

2 Referred to throughout this report as "carbon dioxide equivalent emissions," "CO_2 equivalent," or "CO_2e" emissions.

Table 1. Benefits by Smart Grid capability per customer per year

Capability	Direct Economic Benefits	Reliability Improvement	CO_2 Equivalent Reduction[3]	Indirect Economic Benefits[4]	Customer Choice Benefits
Integrated Volt/ VAr Control	\$11.24–32.01	Improved power quality (value not quantified)	Likely – 372 lbs.	Likely – \$2.59	
Remote Meter Reading	\$13.68–23.92		Possible	Possible	
Time-Varying Rates	\$2.00–19.98		11–110 lbs.	\$0.08–0.76	Yes
Prepayment and Remote Dis-/ Reconnect	\$7.82–19.56		30–76 lbs.	\$0.21-0.53	Yes
Revenue Assurance	\$3.00				
Customer Energy Mgmt.	\$0.77–1.92		14–34 lbs.	\$0.10–0.24	Yes
Service Outage Management	\$1.18	4.5% 4.9 minutes		\$8.82	
Fault Location and Isolation		20.5% 22.3 minutes		\$40.14	
Renewable Generation Integration	Possible	Likely	Likely		Yes
TOTALS	\$39.69–101.57	25% 27.2 minutes	55–592 lbs.	\$49.35-53.08	Yes

It is important to note that no single utility necessarily has all of these capabilities and each utility's results could vary significantly from these estimates. The most significant drivers of benefits and opportunities for improvement are described for each capability in this review.

3 Carbon dioxide reductions are estimated at 1.22 lbs. per kWh, per U.S. Environmental Protection Agency, "eGRID 2012 Subregion GHG Output Emission Rates for Year 2009." Table 1, column = Total Output Emissions Rate (lb/MWh), April 2012. http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2012V1_0_year09_SummaryTables.pdf.

4 The value of carbon emissions reductions is estimated at \$14.00 per metric ton (the price for a CO_2 emissions permit in the May, 2013 California auction). The value of an avoided minute of service outage is estimated at \$1.80 based on a recent Lawrence Berkeley National Laboratory study; see "Estimating the Economic Productivity Impact of Service Outages" in the appendices for more information.

Benefit Drivers

Our analysis indicates that four drivers explain most of the variation in the available benefits.

Table 2. Drivers of Smart Grid capability benefits

Capability	Utility Operating Characteristics	Customer Participation and Behavior	Speed of Cost Reduction and Recognition	Market Prices for Electricity and Capacity
Integrated Volt/VAr Control	X			X
Remote Meter Reading	X		X	
Time-Varying Rates		X		X
Prepayment and Remote Dis-/Reconnect	X	X		X
Revenue Assurance				X
Customer Energy Management		X		X
Service Outage Management	X			
Fault Location and Isolation	X			
Renewable Generation Integration	X	X		X

There appear to be some opportunities available to increase the benefits of Smart Grid capabilities through policy. As one example, traditional ratemaking practices may not encourage utilities to reduce sales volumes between rate cases. Once electric rates are set in a rate case, reductions in sales volume below anticipated levels reduce the likelihood that a utility will be able to cover its costs. Several Smart Grid capabilities discussed in this review, including Integrated Volt/VAr Control and time-varying rates, derive a significant proportion of available economic benefits via reductions in sales volumes. Other regulatory rules and norms may require revisions to enable some customer economic benefits, for instance billing and payment program innovations. The SGCC hopes this review will help stakeholders work together in pursuit of policy solutions that enable customer equity, provide customers with choices, and encourage utility investment, while maximizing available benefits for all customers.

Costs by Smart Grid Component

The average Smart Grid cost per customer, based on budget information from U.S. utilities' applications for the U.S. Department of Energy's Smart Grid Investment Grant (SGIG) program funds, is presented in Table 3 by component.

Table 3. Average cost per customer by Smart Grid component

Smart Grid Component	Sample Size	Average Cost per Customer
Smart Meter	24 projects	$291.54
Distribution Automation	12 projects	$63.64

In addition to these costs, we assume utilities will make annual expenditures equal to 4 percent of initial Smart Grid investments to operate and maintain hardware, software, and communications networks.[5]

Benefit-Cost Summary

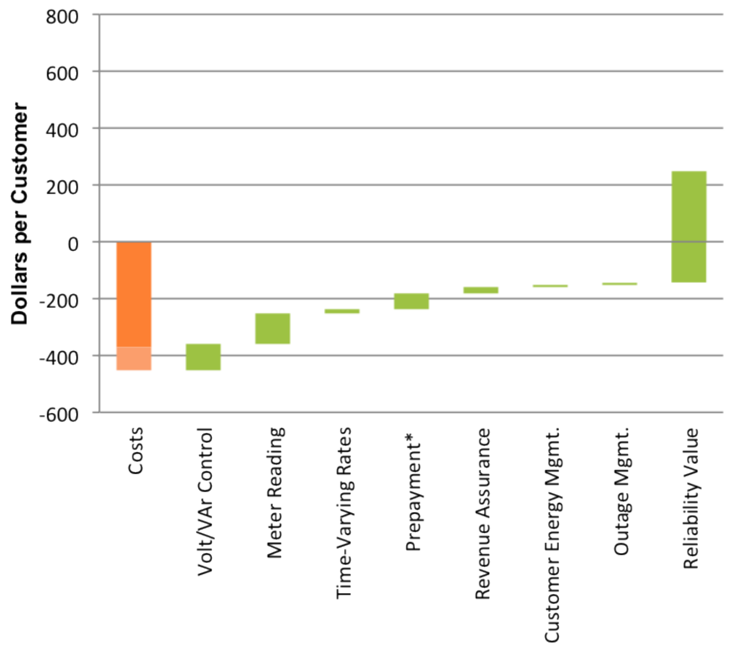
Figure 1 summarizes the Net Present Value (NPV)[6] of benefits and costs for the Reference Case, while Figure 2 does so for the Ideal Case. We assumed a 13-year project life, incorporating 3 years of implementation and 10 years of operation. Based on available research and incorporating the Reference Case and Ideal Case assumptions detailed in this report, we find the ratio of benefits to costs range from 1.5–2.6 to 1 in the Reference Case and Ideal Case, respectively.[7] Subtracting the NPV of total costs from total benefits (direct and indirect) yields net benefits of approximately $247 per customer in the Reference Case and $713 per customer in the Ideal Case.

5 Harvey Kaiser, "Capital Renewal and Deferred Maintenance Programs," APPA Body of Knowledge, 2009, 9.

6 Net Present Value (NPV) is an analytical technique for converting future benefits and costs into present-day dollars for comparative purposes. Please see Section 5, "Costs of the Smart Grid," for more information.

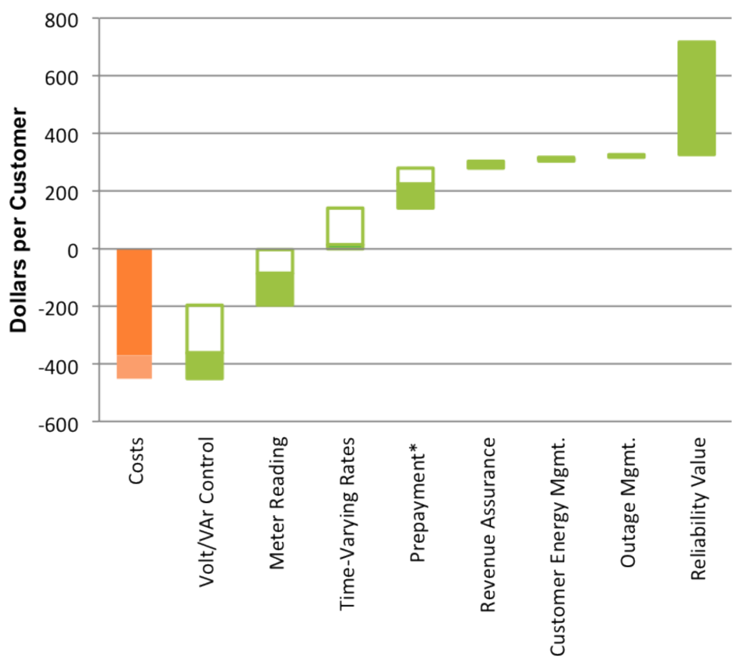
7 Reference Case benefit to cost ratio = ($306.95 + $390.27)/$449.82 = 1.5 (to 1); Ideal Case benefit to cost ratio = ($772.75 + $390.27)/$449.82 = 2.6 (to 1).

Figure 1. Smart Grid costs and benefits by capability: Reference Case



* Includes remote disconnect and reconnect benefits

Figure 2. Smart Grid costs and benefits by capability: Ideal Case



* Includes remote disconnect and reconnect benefits

Open boxes represent the difference in benefit between the Reference Case and the Ideal Case.

Conclusions and Recommendations

The research presented in this review indicates that grid modernization creates direct and indirect economic benefits for customers in excess of costs. The research also indicates that the Smart Grid delivers significant environmental benefits through conservation and renewable generation integration. Opportunities to optimize these benefits are available through a holistic approach involving customer engagement, utility operations, and regulatory/governance systems. The SGCC encourages all stakeholders (utilities, regulators, advocates, and customers) to collaborate in pursuit of optimizing these benefits.

Looking forward, candid conversations among stakeholders about the critical role that the electric distribution grid plays in a community and the kind of grid a community wants to have are essential. Grid upgrades require long lead times; flexibility and reliability must be designed and built well in advance of when they will be needed. The grid we use today was not designed for the demands society seems poised to place on it in the future. Communities need to be asking key questions about the kind of grid they want, the costs required to build it, and priorities and trade-offs they can agree upon.

As the role electric distribution plays in communities' economic vitality and sustainability increases, a new dynamic is needed in the nature of relations among distribution utility stakeholders. This review can serve as a reasonable starting point for the evolution of a new dynamic, and the SGCC hopes stakeholders embrace it and its message in the spirit of objectivity and collaboration in which it has been researched and developed.

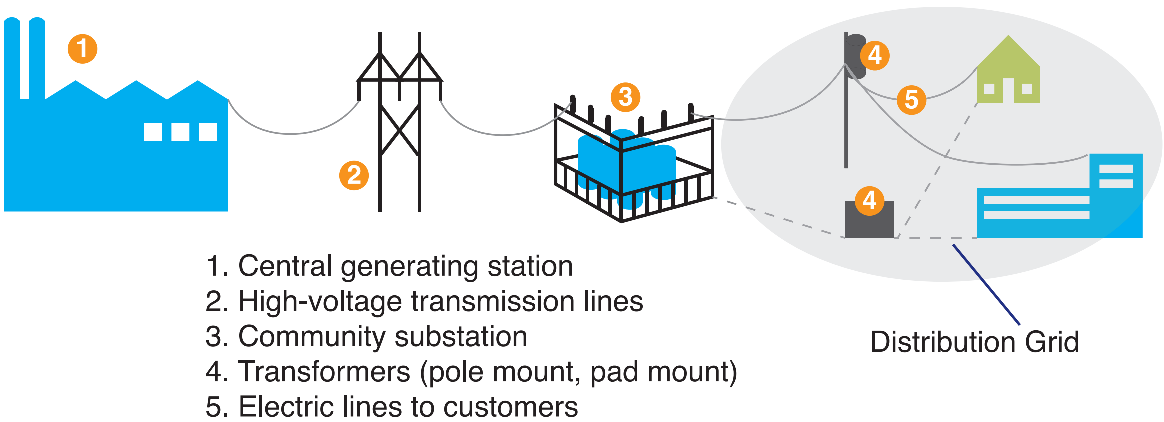
2. INTRODUCTION

What Is a Smart Grid?

The definition of the Smart Grid is presented here only to establish a foundation. What the Smart Grid actually accomplishes – and why stakeholders might want one – is addressed throughout this review.

In recent decades, many industries have grown or perished from the advances made in information and communication technology. However, electric utility systems are still largely operated today in much the same way they were in the early 20th century. Central generating stations produce electric power that is transmitted via high-voltage transmission lines to local community substations. Several primary distribution lines typically extend from each substation, feeding a network of wires and equipment – the distribution grid, or simply "the grid"– that carry electricity to homes and businesses. The distribution grid is the section of the system between the substations and the customers and is the focus of this review.

Figure 3. The distribution grid and its role in the electric utility system



The term "Smart Grid" refers to the computerization of the traditional distribution grid. Until recently, the need to computerize the grid and the communication and information technologies required to do so in a cost-effective manner did not exist. This review will show that the increasing demands society is placing on the grid make computerization more valuable than ever, while advances in technology have made computerization more cost-effective than ever.

How can the traditional grid be computerized? Consider how moving from a traditional grid to a Smart Grid is like moving from a pen and paper to a computer. A computer consists of sensors – such as a keyboard and mouse – that translate and communicate a user's inputs to the computer for information processing and storage. Programs on the computer convert user inputs into spreadsheets or other valuable documents, helping people share information and make decisions. As the inputs change, the shared information and decisions change readily with little or no additional effort. The benefits of using a home computer over pen and paper are fairly clear.

A Smart Grid resembles the computer. Sensors in various locations on the grid collect information on grid operating conditions – including electricity volumes, strengths, and other characteristics – and transmit that information (in some instances continuously and/or instantaneously) to utility computers. These computers can automatically make changes to grid equipment settings without human intervention, continuously and/or instantaneously if needed. In many cases these changes can proactively address issues before they create problems for customers. Information can also be stored for future use, analysis, and decision making by people; for example, in deciding which infrastructure to upgrade based on detailed grid operating data.

In a traditional grid, real-time operating data are not generally available beyond the community substation. To obtain data from the distribution grid, service investigation teams place temporary data-recording devices in select locations, typically only after customer complaints are received. Traditional grid information is limited in timeliness, because it is collected and analyzed long after it has been recorded. Additionally, traditional grid equipment is adjusted only periodically, with many utilities using default "winter" and "summer" settings that suboptimize grid efficiency. Most traditional grid equipment cannot be controlled remotely, so any adjustments generally require the dispatch of service crews.

Why Might Customers Want a Smart Grid?

What does grid computerization offer to utility customers? The computerization of the telephone grid in the late 1980s and early 1990s offers some useful analogies that electric utility customers may be able to appreciate. When the telephone grid was computerized, many new services were suddenly made available to customers, including call forwarding, call waiting, and voice mail. The computerization of the electric grid also offers new capabilities to customers and to utilities, as well. Customers can access electric usage details and money-saving new rate options. Many other new capabilities not immediately apparent to customers are employed by utilities to customers' benefit – reducing operating costs, improving grid efficiency, reducing service outages, and reliably accommodating customer-owned generation such as photovoltaic (PV) solar and demanding new loads such as electric vehicles. In this review we identify and summarize research completed to quantify the benefits of these capabilities and present it in the context of associated costs.

What Are the Components of a Smart Grid?

There are two primary components of a Smart Grid, which can be implemented more or less independently of one another, although there can be advantages to implementing them together. Each component can be implemented in a number of ways, though the details have been intentionally simplified in this review to facilitate presentation and analysis. These two components are Smart Meters (also known as Advanced Metering Infrastructure, or AMI[8]) and Distribution Automation.

Smart Meters

Smart Meters are digital electric meters that take the place of traditional mechanical meters. Traditional mechanical meters use magnets to measure the electric current flowing through the wires leading into a customer's home; the interaction between the magnets causes a metal disk to spin at a rate proportional to the flow of electric current. The disk revolutions are simply counted by the meter, which is read monthly by a utility employee for billing purposes.

Like a traditional meter, a Smart Meter measures electric current. It also stores information and receives and responds to commands and status inquiries from the utility. Smart Meters are much more accurate than mechanical meters, can detect tampering, and can alert the utility when they lose power. Specific Smart Meter capabilities examined in this report include remote meter reading, time-varying rates, prepayment and remote service disconnect and reconnect, revenue assurance, customer energy management, and service outage management.

Distribution Automation

Distribution Automation involves the section of the Smart Grid between the Smart Meter and the local community substation. Although some parts of many utilities' traditional grids have been automated to a limited degree for some time, Distribution Automation is a much more intensive and focused effort to computerize and/or automate grid operations. Distribution Automation capabilities are largely imperceptible by customers, but research indicates their aggregated benefits are potentially significant. These benefits are presented in this review and include improvements in grid efficiency, grid reliability, and the amount of renewable generation (such as PV solar) the grid can reliably accommodate. Specific Distribution Automation capabilities examined in this report include Integrated Volt/VAr Control (IVVC), fault location and isolation, and renewable generation integration.

8 "AMI" generally refers to the Smart Meters as well as associated communications networks, data storage, and data processing systems; we include all of this when use the term "Smart Meter."

Secondary Research Methods Employed in This Review

The SGCC employed a systematic secondary research method to identify and incorporate reference sources included in this review. We considered two types of research for each Smart Grid capability:

- Controlled studies, which we refer to as "studies"
- Surveys and informed analyses, which we refer to as "estimates"

We gave priority to controlled studies wherever available.

Characterization of Benefits in This Review

We have noted a tendency for many researchers, regulators, and utilities to distinguish between "economic benefits to utility operations" and "economic benefits to customers." In cost-based ratemaking, any and all economic benefits to utility operations eventually flow through to customers in future rate cases. Though the timing of these future rate cases is critical if customers are to promptly receive utility operating benefits in the form of lower rates, this distinction is beyond the scope of this review. Accordingly, we simplify all economic benefits found in available research to gross "per customer per year" benefits in this review (unless otherwise noted).[9]

This "per customer per year" metric is different than "per participant per year," in that some Smart Grid benefits accrue disproportionally to customers who participate in certain programs. For example, customers who participate in time-varying rates receive greater benefits than those who do not. Though we note these where appropriate, we average such benefits across all customers (participants and nonparticipants) to facilitate the comparisons to costs.

In order to capture the variation in actual experience with Smart Grid, we present a range of benefits for many capabilities. Where a range is presented, the low end represents what we refer to as the "Reference Case," and the high end represents what we refer to as the "Ideal Case." The Reference Case is based upon conservative assumptions typical of the average capability deployment today. The Ideal Case, on the other hand, represents "the state of the possible" if benefit drivers are thoughtfully optimized.

With this brief introduction to the Smart Grid as it is typically deployed and how it is organized and presented in this review, let's proceed to examine the customer benefits of Smart Meters and Distribution Automation as found in research completed to date.

9 For a more thorough discussion of this topic, see the discussion on traditional ratemaking in "Technical and Economic Concepts Related to the Smart Grid – A Guide for Consumers," available from the SGCC.

3. DIRECT BENEFITS TO CUSTOMERS

In this section, we will review the research findings available to date on the direct benefits that Smart Grid capabilities can deliver to customers. We will examine the Smart Grid capabilities individually, beginning with those which research indicates offer the greatest potential rate relief or conservation benefits realized on customer bills, including:

- Integrated Volt/VAr Control
- Remote meter reading
- Time-varying rates
- Prepayment programs and remote disconnect/reconnect
- Revenue assurance
- Customer energy management
- Service outage management

Integrated Volt/VAr Control

One of the biggest potential Smart Grid benefits is created by a capability called Integrated Volt/VAr Control (IVVC), which helps utilities optimize the power delivered to customers.

	Economic	Reliability	Environmental	Customer Choice
Integrated Volt/ VAr Control Benefits	\$11.24–32.01 per year	Yes but unquantified	Likely – 372 lbs. CO_2e/year	

Description and Value Propositions of Integrated Volt/VAr Control (IVVC)

Integrated Volt/VAr Control helps utilities more effectively manage voltage and power factor[10] on their distribution lines. IVVC can help lower average voltage on a distribution line while ensuring adherence to minimum voltage standards. By lowering the average voltage, utilities can reduce the energy used by customers without any adverse impact on those customers.

For a more detailed understanding of voltage, power factor (or VAr), and how IVVC works to create economic, reliability, and environmental benefits, readers are encouraged to consult the companion report "Technical and Economic Concepts Related to the Smart Grid – A Guide for Consumers," available from the SGCC.

10 Power factor is a measure of the productive component of energy in a unit of electricity. A distribution grid power factor of 98 percent or 99 percent is considered excellent performance.

Economic Benefits of Integrated Volt/VAr Control

IVVC can help utilities reduce required capacity during peak demand periods and, if used on a continual basis, reduce overall energy use. We find the economic benefits range from $11.24 to $32.01 per customer per year, depending on how a utility uses IVVC.

The typical IVVC implementation is used by utilities during periods of peak demand. An Xcel Energy Smart Grid study found that IVVC helped reduce distribution line voltage from an average of 121 volts to 116 volts, yielding a 3.25 percent reduction in peak demand.[11]

Utilities can also use IVVC on a continuous basis to reduce the energy used by customer loads throughout the year. A study by Ameren Illinois of its continuous voltage reduction test on two distribution lines found reduced energy use in all seasons of the year regardless of distribution line characteristics.[12]

Table 4. Percent reduction in electricity used for each 1 percent reduction in voltage

Distribution Line Type	Summer	Fall
Urban	0.78%	1.24%
Rural/Urban	0.97%	0.44%

Likewise, the aforementioned Xcel Energy Smart Grid study found that IVVC used on a continuous basis helped reduce customer electricity use by 2.7 percent.[13]

Please see the appendices for details on how we calculated the annual economic benefit from the results of these studies. The Ideal Case benefit is reasonably consistent with the Ohio Public Utility Commission's evaluation of Duke Energy Ohio's deployment, which estimated an annual benefit of $35.87 per customer per year with continuous application of IVVC.[14]

11 Xcel Energy, *SmartGridCity™ Demonstration Project Evaluation Summary* (report to the Colorado Public Utilities Commission), December 14, 2011, 62.

12 Electric Power Research Institute, *The Smart Grid Demonstration Initiative 5-Year Update,* August 1, 2013, 5.

13 Xcel Energy, *SmartGridCity™ Demonstration Project Evaluation Summary* (report to the Colorado Public Utilities Commission), December 14, 2011, 61.

14 $24.6 million in savings divided by 685,859 customers. U.S. Energy Information Administration, *2011 Annual Electric Power Industry Report,* File 2 (retail revenue, sales, and customer counts by state and class of service). Note: includes bundled (electricity and distribution service) and distribution only customers, Duke Energy Ohio.

Reliability Benefits of Integrated Volt/VAr Control

Although less obvious than service outages, power quality events can cause customer disruptions including flickering lights, tripped circuit breakers, and issues with computers and motors.[15] Although we found no specific research quantifying the degree to which IVVC improved power quality, some anecdotal evidence is available. Xcel Energy's study of its Boulder, Colorado Smart Grid deployment (of 46,000 customers) found that customer power quality complaints fell from an average of 30 annually pre-implementation to zero post-implementation.[16]

Environmental Benefits of Integrated Volt/VAr Control

IVVC offers carbon dioxide emissions reduction benefits in direct relation to electricity usage reductions. Applying U.S. Environmental Protection Agency estimates on carbon dioxide equivalent emissions per kilowatt hour,[17] we estimate IVVC can reduce carbon dioxide emissions by 372 pounds per customer per year when used continuously.

There are also likely environmental benefits from peak load reduction, as the use of less efficient peaking plants (generally single-cycle natural gas plants) can be replaced with more efficient plants designed for intermediate use (generally combined-cycle natural gas plants). We found no research to quantify the size of this environmental benefit.

Drivers of Integrated Volt/VAr Control Benefits

	Utility Operating Characteristics	Customer Participation and Behavior	Speed of Cost Reduction and Recognition	Market Prices for Electricity and Capacity
Integrated Volt/VAr Control	X			X

Utilities that perform relatively poorly on optimizing power factor and average voltage will likely experience greater improvements by employing IVVC than utilities that perform relatively well on these measures. Additionally, the marginal cost of generation and cost of "peaker" generation plant construction impact the economic benefit available; those areas that have higher costs will experience higher benefits.

As noted above, using IVVC on a continual basis – rather than only during periods of peak demand – can drive substantial economic and environmental benefits.

15 Electric Power Research Institute, *The Cost of Power Disturbances to Industrial and Digital Economy Companies* (study conducted by Primen for the EPRI), June 29, 2001, 4-3.

16 Xcel Energy, *SmartGridCity™ Demonstration Project Evaluation Summary* (report to the Colorado Public Utilities Commission), December 14, 2011, 85.

17 1.22 lbs. CO_2e/kWh.

Remote Meter Reading

Among other capabilities, Smart Meters offer utilities the ability to implement remote meter reading. Remote meter reading offers significant reductions in utility operations costs, particularly for those utilities that have not already implemented remote meter reading through other means prior to Smart Meter installation.

	Economic	Reliability	Environmental	Customer Choice
Remote Meter Reading Benefits	$13.68–23.92 per year		Possible	

Remote Meter Reading Description and Value Creation

Remote meter reading enables a utility to obtain electric usage data from meters for billing purposes without sending personnel to read each meter. This avoids the expense, traffic, and potential safety issues (for example, from slips, dog bites, or auto accidents) of sending meter readers to manually read electric meters every month or for "special" meter reads, such as when a customer moves.

In addition to benefits related to labor and vehicle savings, Smart Meter installations can significantly reduce the amount utilities spend on replacing worn traditional meters, at least until those meters begin to age.

Economic Benefits of Remote Meter Reading

We find the economic benefits of remote meter reading to vary between $13.68 and $23.92 per customer per year, depending chiefly on utility operating characteristics prior to implementation. For the Reference Case, we assume that a utility has already automated monthly meter reads via a capability called Automated Meter Reading (AMR), and therefore include only reductions in special meter reads and non-labor cost savings. The Ideal Case assumes that all meter reads – including routine monthly reads – were previously completed manually.

A study by the Ohio PUC of the benefits of Duke Energy's Ohio Smart Grid deployment found a savings of $10.18 per customer per year in special meter reads.[18] The same study also found that reductions in non-labor expenses related to reductions in meter testing, repair, and replacement amounted to $3.50 per customer per year,[19] bringing the total Reference Case economic benefits to $13.68 per customer per year.

18 $6.98 million annual savings divided by 685,859 customers. Public Utilities Commission of Ohio, *Duke Energy Ohio Smart Grid Audit and Assessment,* June 30, 2011, 80.

19 $2.4 million annual savings divided by 685,859 customers. Ibid., 83–84.

The Ohio PUC study indicated savings of $10.24 per customer per year in routine monthly meter reads.[20] Hence, in the Ideal Case – a utility moving from fully manual to fully automated meter reading – customer economic benefits total $23.92 per customer per year.

Drivers of Remote Meter Reading Benefits

	Utility Operating Characteristics	Customer Participation and Behavior	Speed of Cost Reduction and Recognition	Market Prices for Electricity and Capacity
Remote Meter Reading	X		X	

In addition to whether a utility has previously implemented AMR, other operating characteristics serve as drivers of potential benefits. For example, a rural utility with low customer density will have higher pre-implementation meter reading costs than an urban utility with a high customer density. Duke Energy Ohio's service territory, which includes Cincinnati, its suburbs, and surrounding rural areas, is fairly typical with respect to customer density.

Additionally, rules surrounding customer move outs and move ins impact the available benefits. When responsibility for a particular premises' electric bill passes from one occupant to another, some utilities read the meter on the move-out date, while others simply prorate a month's usage based on the move-out date. Those utilities reading the meter on customers' move-out and move-in dates have much higher meter-reading costs than utilities avoiding such reads through proration, and therefore experience greater savings from remote meter reading.

Finally, rules around how customers who opt out of Smart Meter installation are treated can impact the available benefits. Every customer who opts out of Smart Meter installation increases a utility's meter-reading costs. In some cases, whether by policy or by regulation, utilities do not charge the full incremental costs of manual meter reading to those customers who refuse Smart Meters or associated remote communications capabilities.

When the full incremental cost of manual meter reading is not charged to those customers who opt for it, the remaining customers must pick up the difference. Several issues contribute:

- The fixed costs of operating and maintaining two meter-reading systems is significantly higher than maintaining a single meter-reading system.
- The variable incremental cost of manually reading the meters of a limited number of customers spread out over a wide service territory is likely much higher on a "per manual read customer" basis than the meter-reading costs per customer prior to Smart Meter installation.

20 $7.02 million annual savings divided by 685,859 customers. Ibid., 78.

Those utilities that do charge a fee for manual meter reading generally charge a one-time set-up fee (generally \$20–\$75) and an ongoing monthly charge (generally \$10–\$25).[21] The District of Columbia PSC has ordered an estimate, not yet completed as of this review's publication, of PEPCO's manual meter-reading costs post-AMI deployment (Formal Case 1056).

Time-Varying Rates

By recording both a customer's electric consumption and the day and time when it is consumed, Smart Meters facilitate time-varying rate offerings. However, the drivers of available benefits of time-varying rates are among the most complex of the Smart Grid capabilities discussed in this report, and require strong collaboration between utilities, regulators, and customers to optimize.

	Economic	Reliability	Environmental	Customer Choice
Time-Varying Rates Benefits	\$2.00–19.98 per year		11–110 lbs. CO_2e/year	YES

Time-Varying Rate Description and Value Creation

Because most utility customers have only experienced flat-rate pricing, they do not realize that the cost of electricity varies by the time of day or day of the year. Electricity is, however, subject to the same laws of supply and demand that drive the pricing of other goods and services. Utilities pay more for electricity during periods of peak demand – such as a hot summer afternoon with a high demand for air conditioning – and less during off-peak periods, such as a cool fall night.

The flat-rate pricing for electricity that most consumers are familiar with is a blended average of the actual cost of electricity, and it obscures the variance in electricity costs from consumers. This causes what economists call "inefficiency," because customers have no incentive to shift their usage from peak to non-peak times.

Time-varying rates reduce or eliminate this inefficiency by providing customers with an opportunity to reduce their electric bills by shifting their usage from peak to non-peak times. This usage shifting can even create benefits for customers who do not participate in time-varying rates because utility investments in new generation plants – for which all customers pay – can be delayed or avoided.

21 Will McNamara, *AMI Opt Out: Policies, Programs, and Impact on Business Cases* (white paper), West Monroe Partners, 2012, 11.

Economic Benefits of Time-Varying Rates

The economic benefits of time-varying rates consist of two components. The first is a result of the shift in when customers participating in time-varying rates consume electricity. The second is a result of participating customers reducing their overall electricity use. In total, and depending on the variables described in the next section, these benefits range from $2.00 to $19.98 per customer per year.

There are many types of time-varying rates, each with its own pros, cons, and potential benefits.[22] Controlled studies indicate 10 percent to 30 percent reductions in electricity demand at a given point in time for most types of time-varying rates, with certain types generating point-in-time reductions as high as 40 percent or even more.[23]

Research also indicates that most customers participating in time-varying rates not only shift usage from high-priced to low-priced periods, they also reduce electric use overall. This is due in part to the fact that customers participating in time-varying rates are more aware of their overall energy usage, and in part because reductions in use do not always require a commensurate increase. For example, a customer who turns off lights during a peak period has no need to turn on more lights than they otherwise would during a nonpeak period. A survey of available research on the conservation impact of time-varying rates indicates a 4 percent reduction in overall electric use is likely among customers participating in such rates.[24]

Table 5 summarizes economic benefits from time-varying rates for the Reference Case and Ideal Case. Please see the appendices for more detail on the assumptions and calculations.

Table 5. Summary of economic benefits from time-varying rates

	Reference Case	Ideal Case
Customer Participation	2%	20%
Peak Demand Reduction	$1.38	$13.83
Energy Conservation	$0.62	$6.15
Total	$2.00	$19.98

22 For more information, see the discussion on time-varying rates in “Technical and Economic Concepts Related to the Smart Grid – A Guide for Consumers,” available from SGCC.

23 Ahmad Faruqui and Jenny Palmer, “The Discovery of Price Responsiveness – A Survey of Experiments Involving Dynamic Pricing of Electricity.” March 12, 2012.

24 Chris King and Dan Delurey, “Efficiency and Demand Response: Twins, Siblings, or Cousins?” *Public Utilities Fortnightly,* March 2005, 55.

It is important to note these are the total benefits to an entire customer base for a utility offering time-varying rates under these assumptions. Depending on the details of specific time-varying rate designs, these benefits are split in some manner between the customers who participate in the rate (who obtain direct rewards by participating) and those who do not (and simply enjoy the lower costs associated with delayed or avoided investments in the form of lower overall rates). This means customers who participate in these rates and shift their usage are likely to receive much more than $2.00–$19.98 in benefits annually, and customers who do not will receive much less.

Environmental Benefits of Time-Varying Rates

Time-varying rates offer carbon dioxide emissions reduction benefits in direct relation to the conservation effect. Applying U.S. Environmental Protection Agency estimates on carbon dioxide equivalent emissions per kilowatt hour, we estimate time-varying rates can reduce carbon dioxide emissions by between 11 pounds and 110 pounds per customer per year.[25]

Customer Option Benefits from Time-Varying Rates

As described in this section, time-varying rates certainly offer customers an opportunity to reduce their electric bills. Lower electric bills and/or increased control over them are likely to increase the satisfaction of participating customers.

Drivers of Time-Varying Rate Benefits

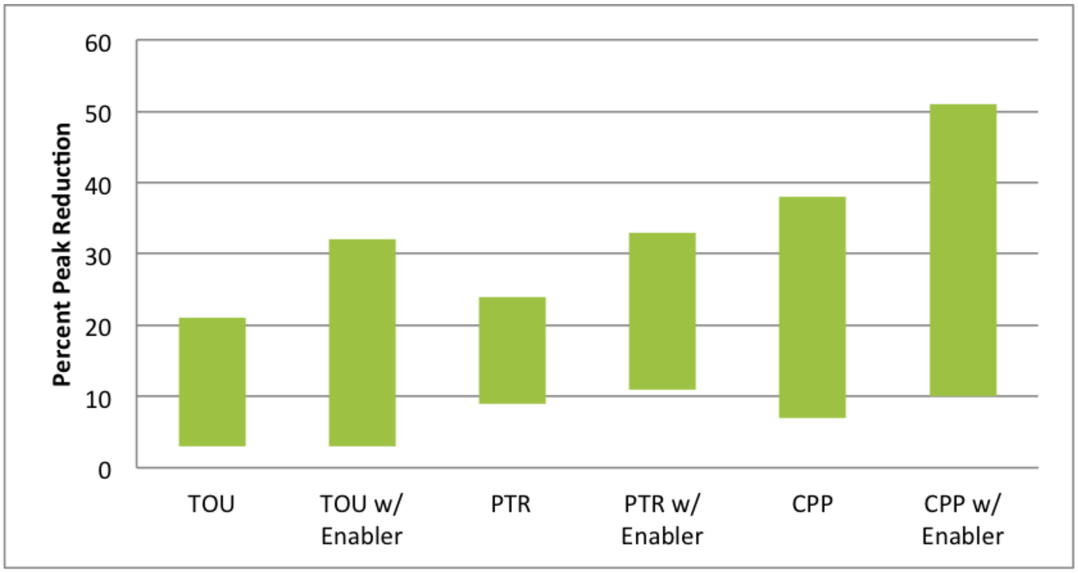
	Utility Operating Characteristics	Customer Participation and Behavior	Speed of Cost Reduction and Recognition	Market Prices for Electricity and Capacity
Time-Varying Rates		X		X

The single biggest driver of the available benefits of time-varying rates is customer participation rates. There are a number of actions stakeholders can take to increase customer participation rates, though many of them – including changing misperceptions that customers may hold and addressing structural winners and losers – can be challenging. For more detail, please refer to the "Technical and Economic Concepts Related to the Smart Grid – A Guide for Consumers," available from SGCC.

The second biggest driver is the extent to which customers shift and/or reduce their electric usage. Higher variations between off-peak and on-peak pricing lead to higher shifting behaviors. Enabling technologies such as programmable thermostats can also drive greater shifting. See Figure 4 for a summary of different rate designs and the range of usage shifting for each.

25 See calculations in the appendices.

Figure 4. Summary of time-varying rate impact study results[26]



Notes to Figure 4 (highest and lowest results removed from each study type):
TOU: Standard Time-Of-Use rate design; *n* = 37 studies.
TOU w/Enabler: TOU with enabling technology; *n* = 14 studies
PTR: Peak-Time Rebate rate design; *n* = 12 studies
PTR w/Enabler: PTR with enabling technology; *n* = 17 studies
CPP: Critical Peak Price rate design; *n* = 23 studies
CPP w/Enabler: CPP with enabling technology; *n* = 21 studies

Prepayment Programs and Remote Disconnect/Reconnect

Although a few utilities have offered prepayment programs using traditional meters, Smart Meters make such programs significantly easier to implement. Smart Meters' real-time, two-way communications and remote service disconnect/reconnect capabilities enable more cost-effective administration of such programs by utilities and simplify participation for customers.

	Economic	Reliability	Environmental	Customer Choice
Prepayment Program Benefits	\$7.82–19.56 per year		30–76 lbs. CO_2e/year	YES

26 Ahmad Faruqui and Jenny Palmer, "The Discovery of Price Responsiveness – A Survey of Experiments Involving Dynamic Pricing of Electricity." March 12, 2012.

Prepayment Program Description and Value Creation

Most customers are billed and pay for electricity after they use it. However, some utility customers appear to prefer to pay as they go. Smart Meters enable utilities to more easily offer such programs, which drive reductions in energy use, increases in customer satisfaction, and decreases in utility operating costs.

Research indicates that customers who participate in prepayment programs use less electricity after signing up for the program than they did before. Almost all prepayment programs involve some sort of display informing participants of their account balance, generally expressed in days of electricity left based on current usage rates. These displays serve as a continuous feedback mechanism, making customers constantly aware of the rate at which they are using electricity. As discussed in the "Customer Energy Management" section, feedback is a critical component of energy conservation.

Electric rates are set at a level sufficient to cover utility operating expenses, including those related to billing and collection. Prepayment programs theoretically should reduce several types of billing and collection expenses, including the cost of printing and mailing bills, bad debt write-offs, service visits, and interest expense. Of these, the reduction in service visit costs is by far the most significant, as Smart Meters' remotely controlled disconnect/reconnect switches alleviate the need for service visits to collect or prompt payment on past-due accounts, post notices, disconnect service, or reconnect service.[27] Utility interest expenses are reduced with prepayment, as utilities need not borrow money to fund the difference between the time traditional billing customers use electricity and the time they pay for it.

Economic Benefits

The economic benefits from prepayment programs stem from the conservation effect of program participants – which accrue directly to participants – and in the reduced billing, collection, and interest expense such programs produce. We find a total benefit of $7.82–19.56 per customer per year from these two factors.

A controlled study conducted upon the introduction of a prepayment program by the Oklahoma Electrical Cooperative finds a weather-adjusted 11 percent reduction in electric usage by prepayment customers after joining the program.[28] Additionally, the utility operating one of the most extensive and longest-running prepayment programs in the U.S., the Salt River Project in Arizona, estimates its prepayment customers reduce electric use by 12 percent after joining.[29]

27 This is a particularly expensive proposition, as two or three truck rolls with a variable cost of $35–$50 each can be required to post notices, disconnect service, and reconnect service to collect a single $100 payment (for example) on a past-due account.

28 Michael Ozog, *The Effect of Prepayment on Energy Use* (Integral Analytics, Inc. research project commissioned by the DEFG Prepay Energy Working Group), March 2013, 2.

29 Institute for Energy and the Environment, Vermont Law School, *Salt River Project: Delivering Leadership on Smarter Technology & Rates,* June 2012, 18.

Long-standing programs, such as those in the United Kingdom and at the Salt River Project in the U.S., indicate participation rates as high as 13 percent[30] and 12.5 percent,[31] respectively. Because it can take decades for a prepayment program to reach these participation levels, we use a 2 percent participation rate to calculate economic benefits in the Reference Case and a more aggressive 5 percent participation rate for the Ideal Case. The conservation effect using these assumptions ranges from $1.69 to $4.23 per customer per year. Recall that these are benefits spread across the entire customer base for the purposes of comparison to costs. In reality, only participating customers receive the conservation benefit, and it can be significant. Given these assumptions, the average benefit per participant indicated is $84.62 annually. Please see the calculations in the appendices for more detail.

We find no controlled studies quantifying billing, bad debt, collection, and interest expense reductions from prepayment programs. A leading vendor of prepayment program software estimates reductions of $357 to $377 in bad debt, billing, and collection expenses (particularly service truck rolls) per participant per year,[32] while the Salt River Project estimated these savings at $300 per participant per year in 2006.[33] Using industry averages, we estimate an additional annual benefit of $6.65 per participant in reduced interest expense. These savings equate to $6.13 to $15.33 per customer per year for the Reference Case and Ideal Case, respectively. Please see the appendices for additional detail on these calculations.

Environmental Benefits

The environmental benefits associated with prepay programs are primary due to the conservation effect demonstrated by program participants. We calculate 30 pounds annual carbon dioxide equivalent reduction per customer in the Reference Case and 76 pounds annual carbon dioxide equivalent reduction per customer in the Ideal Case.[34]

We find no research quantifying the environmental impact of reductions in service calls avoided through Smart Meter–enabled remote disconnect and reconnect capabilities. As these service calls are made in vehicles, there are likely reduced emissions associated with mileage reductions. However, these reductions are likely to be small relative to the conservation effect.

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30 Department of Energy and Climate Change, *U.K., Smart Metering Implementation Programme: Data Access and Privacy,* April 2012, 25.

31 Chris Villarreal, *A Review of Prepay Programs for Electric Service,* (policy paper of the California Public Utilities Commission, Policy and Planning Division), July 26, 2012, 4.

32 John Howatt and Jillian McLaughlin, *Rethinking Prepaid Utility Service: Customers At Risk* (white paper by the National Consumer Law Center), June 2012, 14.

33 R.W. Beck, *Prepaid Electric Service* (white paper), March 2009, 10.

34 Please see calculations in the appendices.

Customer Choice Benefits

In some cases, consumers may be signing up for prepay due to an inability to qualify for post-pay; however, research indicates that customers who participate in prepayment programs prefer them to post-use billing and payment. Forty-six percent of prepayment program participants give the Salt River Project a 9 or 10 rating on a 10-point "value received considering the amount you pay" score, compared to 37 percent of non-participating customers.[35] A survey of prepayment program participants in Arizona and Texas finds more than half (62 percent) indicate being "very satisfied" with their programs, while an additional 29 percent are "somewhat satisfied" – totaling 91 percent.[36] Asked if they are likely to recommend prepay electric service to family and friends, the same survey finds that 63 percent were "very likely" to recommend doing so, while an additional 25 percent were "somewhat likely."

These results are likely due to the assistance these programs provide in helping customers manage electricity costs. "Control over energy costs and budget" is the reason most respondents in the Arizona/Texas survey cited for participating in prepayment programs.[37]

Drivers of Prepayment Program Benefits

	Utility Operating Characteristics	Customer Participation and Behavior	Speed of Cost Reduction and Recognition	Market Prices for Electricity and Capacity
Prepayment Program	X	X		X

The largest drivers of prepayment program benefits are the customer participation rate and the size of a utility's spending on bad debt, billing, collection, and interest expenses.

35 Bernie Neenan, *Paying Upfront: A Review of Salt River Project's M-Power Prepaid Program* (Technical Update 1020260), Electric Power Research Institute, October 2010, 4-3.

36 EcoAlign, *Prepay Energy's Pathway to Customer Satisfaction and Benefits* (results of consumer research), February 2012, 4.

37 Ibid., 3.

Revenue Assurance

Smart Meters help utilities reduce what they call "unaccounted-for losses." "Lost" electricity is electricity generated and distributed, but not billed, to customers. Traditional cost-based ratemaking includes such losses in customer rates. (To understand the mechanics, interested readers are encouraged to review the discussion on traditional ratemaking in "Technical and Economic Concepts Related to the Smart Grid – A Guide for Consumers," available from the SGCC.)

Lost revenues result from three primary sources: metering errors, theft, and line losses. Here we will address how Smart Meters defend against metering errors and theft.

	Economic	Reliability	Environmental	Customer Choice
Revenue Assurance Benefits (Reference Case and Ideal Case)	$3.00 per year			

Revenue Assurance Description and Value Creation

Smart Meters are both much more accurate than traditional mechanical meters and offer theft detection capabilities unavailable in traditional meters. We will address these capabilities individually.

Meter Accuracy

State regulators generally prescribe the minimum accuracy standards for meters for the investor-owned utilities they regulate, typically within 2 percent (high or low) of actual electric current flow. A study by the Ohio Public Utilities Commission of Duke Energy's Ohio Smart Meter deployment found that the analog meters being replaced were accurate to within 0.53 percent of actual use.[38] Manufacturers of most Smart Meters warrant accuracy to within 0.5 percent of actual use, a four-fold increase in accuracy over most states' regulatory rules. The Ohio PUC study found Smart Meters to be accurate to within 0.167 percent,[39] a threefold increase in accuracy over the old analog meters. Additionally, this study found that traditional meters were much more likely to be slow than Smart Meters. A customer with a slow meter is charged for less electricity than he or she is actually using. All other customers make up for these customers' underpayments in the form of slightly higher rates.

38 "Public Utilities Commission of Ohio, *Duke Energy Ohio Smart Grid Audit and Assessment,* June 30, 2011, 21.

39 Ibid.

Theft Detection

All customers pay the price for electricity theft in the form of higher rates. Smart Meters can help utilities identify electricity theft and catch it earlier, to the benefit of all customers. Each Smart Meter is equipped with sensors alerting the utility to meter removal – even if it is only momentary – or to the presence of magnets, both of which are not detected by traditional meters. However, the sensors do not help in cases in which a meter is completely bypassed. This is where Smart Meters' capability to measure when power is used can help.

Most customers who steal electricity through meter bypass (literally, with wires) do so on a temporary basis. For example, they might only bypass the meter for three weeks out of every four, allowing some usage to register so as not to raise utility suspicion. These customers simply repeat the on-off bypass pattern each month. Traditional meters, which only count the spins of the dial since the last meter read, cannot catch this type of activity. However, utilities with Smart Meters are developing and applying review algorithms to detect such patterns in the detailed usage data Smart Meters offer.

Economic Benefits of Revenue Assurance

The total revenue assurance economic benefit amounts to $3.00 per customer per year, consisting of $1.56 in meter accuracy[40] and $1.44 in theft detection benefits.[41] Of note, the theft detection benefit is net of detection and prosecution costs.

Drivers of Revenue Assurance Benefits

	Utility Operating Characteristics	Customer Participation and Behavior	Speed of Cost Reduction and Recognition	Market Prices for Electricity and Capacity
Revenue Assurance	X			X

It is likely that the greater the average age of the traditional meters that are replaced, the greater the improvement in accuracy and the greater the resultant benefit. In addition, electric rates have an impact. The higher the price per unit of use, the greater the resulting underbillings for a given level of meter error will be. Ohio electric rates are about average compared to the rest of the U.S.[42]

We make no distinction between the Reference Case and the Ideal Case for the revenue assurance benefit, as clear drivers such as customer participation rates are not available to use as a basis for distinguishing between them.

40 $1.07 million in annual revenue divided by 685,859 customers. Public Utilities Commission of Ohio, *Duke Energy Ohio Smart Grid Audit and Assessment,* June 30, 2011, 85.

41 $990,000 annual benefit divided by 685,859 customers. Ibid, 82.

42 Ohio is in the middle quintile, with 40 percent of states reporting higher rates, and 40 percent reporting lower rates. U.S. Energy Information Administration, "Table 5A. Residential Average Monthly Bill by Census Division, and State 2011," Line 66 (U.S. Total), Column D ("Price").

Customer Energy Management

A traditional electric bill indicates how much electricity a customer uses over a month. Smart Meters record how much electricity a customer uses every 10 or 15 minutes, information that many utilities make available to customers so that they can better manage and reduce their electric use.

	Economic	Reliability	Environmental	Customer Choice
Customer Energy Management Benefits	\$0.77–1.92 per year		14–34 lbs. CO_2e/year	YES

Customer Energy Management Description and Value Creation

Many customers have had access to electric bill histories via a secure utility web page for some time. Some utilities even provide comparisons to anonymous neighbors' historical usage data to help customers benchmark their usage. However, the detailed information from Smart Meters takes the concept of energy usage feedback to a whole new level.

Smart Meters enable utilities to provide access to detailed historical usage data (in 10- or 15-minute intervals) and/or real-time usage data. Most utilities installing Smart Meters offer customers access to detailed historical usage data via a secure Internet website or a smartphone application, generally on a one-day lag. Some utilities also offer their customers access to real-time data via an in-home display, web portal, or smartphone app. This latter capability, in particular, has a demonstrated impact on electricity consumption by providing customers with immediate feedback on their usage and the impact of changes they make to their usage.

Economic Benefits of Customer Energy Management

A survey of electric usage display impact research in Canada found an average 7 percent conservation effect.[43] A similar survey covering several decades of research worldwide found a range of 5 percent to 15 percent in conservation effect from direct, real-time usage feedback.[44] Although these are significant decreases in usage, adoption of real-time energy usage displays is likely to be limited for some time.[45] As a result, and using adoption rates of 2 percent to 5 percent for the Reference Case and Ideal Case, respectively, we find the economic benefits from customer energy management to range from $0.77 to $1.92 per customer per year. As with many other participation-dependent Smart Grid capabilities, these economic benefits are typically much higher for customers using real-time data, and minimal or nonexistent for customers not using them.

Environmental Benefits of Customer Energy Management

Environmental benefits accrue directly from the conservation effect of customer energy management. We calculate 14 to 34 pounds per customer per year in carbon dioxide equivalent emissions reduction.[46]

Drivers of Customer Energy Management Benefits

	Utility Operating Characteristics	Customer Participation and Behavior	Speed of Cost Reduction and Recognition	Market Prices for Electricity and Capacity
Customer Energy Management		X		X

The number of customers using real-time usage data is a critical driver of energy management benefits. Research indicates that coupling this information with incentives such as those offered in time-varying rate or prepayment programs can drive greater benefits than either incentives or feedback on their own.[47] Figure 4 summarizes the results of multiple studies, which collectively indicate a greater impact when an incentive program is paired with an enabling technology, such as a real-time energy usage display device.

43 Ahmad Faruqui, Sanem Sergici, and Ahmed Sharif, "The Impact of Informational Feedback on Energy Consumption – A Survey of the Experimental Evidence" (meta-analysis), *Energy* 35, 2010, 1.

44 Sarah Darby, "The Effectiveness of Feedback on Energy Consumption" (literature review), University of Oxford Environmental Change Institute, April 2006, 3.

45 Janelle LaMarche, et al, "Home Energy Management: Products and Trends" (white paper), Fraunhofer Center for Sustainable Energy Systems, 1.

46 Please see calculations in the appendices.

47 Ahmad Faruqui, Sanem Sergici, and Ahmed Sharif, "The Impact of Informational Feedback on Energy Consumption – A Survey of the Experimental Evidence" (meta-analysis), *Energy* 35, 2010, 5.

Service Outage Management

Smart Meters' instantaneous communications capabilities change the way utilities learn of and respond to service outages, reducing service restoration time and cost. Economic benefits are realized when utilities use this capability to avoid unnecessary investigations of outages reported by customers in error.

	Economic	Reliability	Environmental	Customer Choice
Service Outage Management Benefits (Reference Case and Ideal Case)	$1.18 per year	4.5% outage duration reduction		

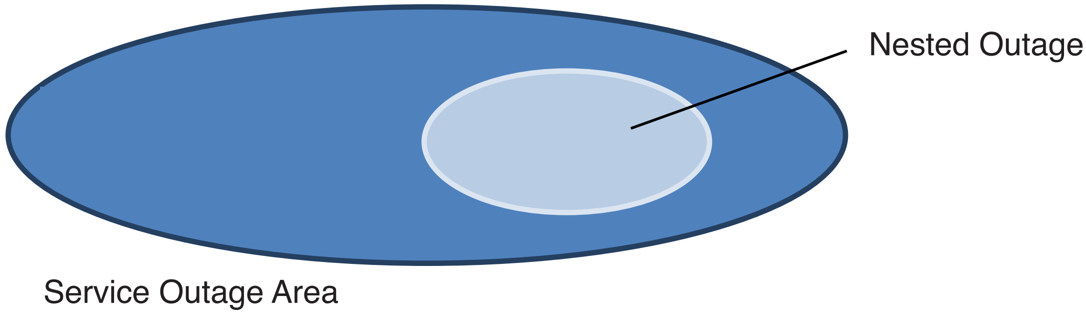
Service Outage Management Description and Value Creation

Utilities have traditionally learned of all but the largest service outages through reports from customers. In fact, an entire software industry segment – outage management systems – has arisen to help utilities log customer outage reports and analyze them in an attempt to determine the extent, nature, and general location of service outages. Unfortunately, customer reports are inherently unreliable; only a small percentage of customers impacted by an outage report it to their utility. Small outages (of one to five homes) can go on for hours before being reported – there is a higher likelihood that no customer is home to detect them – as can outages occurring from midnight to 5 a.m., when most customers are sleeping.

Most Smart Meter models offer a "last gasp" capability, which reports to the utility when the supply of power to the meter is lost. This eliminates or greatly reduces a utility's reliance on customer reports to identify and assess outages. Used in combination with an outage management system, "last gasp" helps utilities learn of outages more quickly and more accurately determine their extent, nature, and general location.

Smart Meters can also respond to utilities' status inquiries. Generally called meter "pinging," a utility can query any Smart Meter to see if it has power. This capability is particularly useful to manage "nested outages" where one outage masks the presence of another, as shown graphically in Figure 5.

Figure 5. Representation of "nested outages"



In a traditional grid, restoration personnel can be unaware of the existence of the nested outage. They repair the larger fault and mistakenly assume that power has been restored to the entire area. Only when customers complain does the utility operating a traditional grid recognize the nested outage. Utilities have traditionally managed this phenomenon by phoning customers to inquire if their power has been restored – a time-consuming, costly, and increasingly ineffective process. With Smart Meter pinging, utilities quickly and accurately verify power restoration and identify nested outages without relying on inbound or outbound telephone calls.

There are concomitant operational benefits that save money. Utilities spend dramatically less manpower (generally overtime and contract labor) understanding the extent and nature of an outage and virtually eliminate the use of resources to verify power restoration.

Additional operational benefits are available from Smart Meter pinging capabilities through reductions in "OK on arrival" service visits. Utilities receive large numbers of outage reports that are not their responsibility to fix, such as when a home's circuit breaker has tripped. With Smart Meter pinging, a utility can instantly and remotely determine if an individual meter has power and help the customer restore power without having to send an employee to investigate.

Service Outage Management Economic Benefits

We find a total expense reduction of $1.18 per customer per year from Smart Meter enhancements to outage restoration and reductions in "OK on arrival" service visits. An evaluation of Duke Energy's Ohio Smart Meter deployment by that state's public utilities commission found that Smart Meters reduce labor costs for power restoration by $1.06 per customer per year.[48] An Xcel Energy study finds the ability to avoid unnecessary "OK on arrival" service visits via meter pinging saves $0.12 per customer per year in operating expenses.[49]

48 $730,000 annual savings divided by 685,859 customers. Public Utilities Commission of Ohio, *Duke Energy Ohio Smart Grid Audit and Assessment,* June 30, 2011, 87–90.

49 $2,700 annually divided by 23,000 customers with Smart Meters. Xcel Energy, *SmartGridCity™ Demonstration Project Evaluation Summary* (report to the Colorado Public Utilities Commission), December 14, 2011, 63.

In addition to these direct cost savings, increased electric service reliability can deliver productivity benefits to local economies. In this review we calculate an indirect economic productivity benefit of $1.80 per customer per minute, and therefore $8.82 in indirect benefits annually from improved service outage management.[50] For more information, see "Estimating the Economic Productivity Impact of Service Outages" in the appendices.

Service Outage Management Reliability Benefits

In a study of the reliability benefits of Smart Meters, Xcel Energy found that outages are reported more quickly, and that the nature and extent of outages – including nested outages – are estimated more accurately. These capabilities produced an average reduction in service outage durations of 4.9 minutes per customer per year,[51] a 4.5 percent decrease in customer minutes per year versus the baseline of 109 minutes per year.[52]

Drivers of Service Outage Management Benefits

	Utility Operating Characteristics	Customer Participation and Behavior	Speed of Cost Reduction and Recognition	Market Prices for Electricity and Capacity
Service Outage Management	X			

Not all utilities have designed their Smart Grids to take advantage of Smart Meters' last gasp capabilities. These utilities typically use sensors located throughout the distribution grid in place of Smart Meters to detect outages. These sensors are not as effective as individual Smart Meters at detecting small (one- to five-home) outages, though utilities employing such an approach point out that sensors can be cheaper than Smart Meters to install (due to smaller quantities) and that large outages are a greater priority than small outages.

We make no distinction between the Reference Case and the Ideal Case for the service outage management benefit, as clear drivers such as customer participation rates are not available to use as a basis for distinguishing between the Reference Case and Ideal Case.

50 Indirect benefit per customer/yr = minutes per customer/yr x value/minute = 4.9 x $1.80 = $8.82.

51 224,000 minutes annually divided by 46,000 customers. Xcel Energy, *SmartGridCity™ Demonstration Project Evaluation Summary* (report to the Colorado Public Utilities Commission), December 14, 2011, 81–83.

52 "Xcel Energy, *Xcel Energy Quality of Service Monitoring and Reporting Plan* (Boulder region, 2008 CAIDI total, including ordinary distribution interruptions only), April 18, 2013.

4. INDIRECT BENEFITS TO CUSTOMERS AND COMMUNITIES

In Section 3 we examined the direct benefits available from Smart Grid capabilities offering potential rate relief or conservation benefits on customers' bills. In this section we will turn our attention toward Smart Grid capabilities offering indirect benefits to customers and communities, focusing on electric distribution reliability and renewable generation integration.

Fault Location and Isolation

In the section on service outage management we discussed how the Smart Grid, and in particular Smart Meters, help utilities learn of outages faster, estimate the scope of outages more quickly and with less labor, and reduce the cost of false outage reports. Distribution Automation capabilities – specifically, fault location and isolation – help utilities find and fix faults more quickly and isolate fault impacts to fewer customers.

	Economic	Reliability	Environmental	Customer Choice
Fault Location and Isolation Benefits		22.3 minutes/ year		

Description and Value Propositions of Fault Location and Isolation

Fault Location

Whereas Smart Meters can provide general information on the nature and extent of service outages, fault location capabilities provide repair crews with exact fault locations. In a traditional grid situation, distribution control centers will analyze the locations of customers calling about outages to try to narrow down the location of a fault to a particular distribution line for repair crews. Repair crews will then drive along the distribution line until a sign of trouble is encountered (for example, a downed line or power pole, tripped pole-mounted fault indicator, or blown fuse). Underground lines present a particular challenge because no physical damage is apparent, and repairs crews must physically examine multiple equipment vaults or cabinets to identify locations by a process of elimination. All of these efforts take a lot of time.

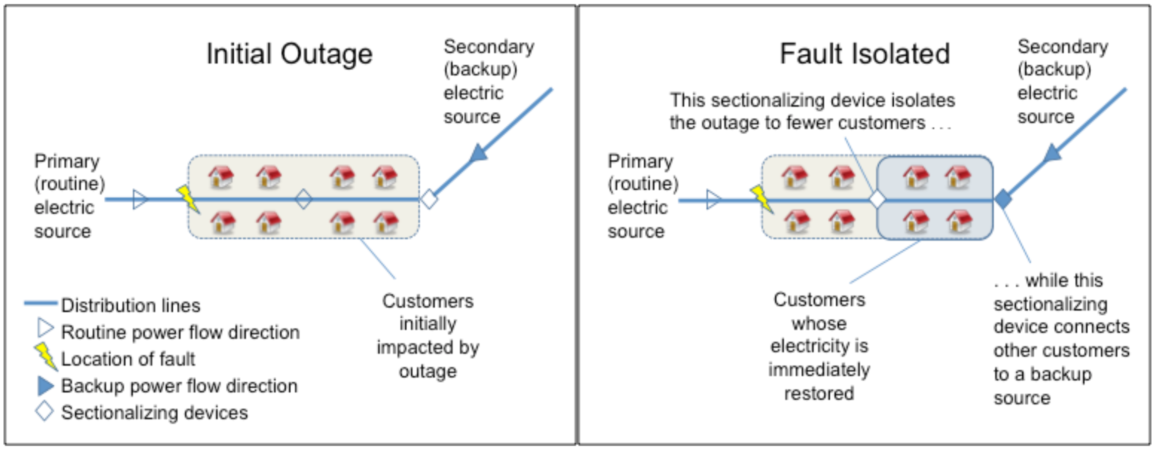
With fault location capabilities, line sensors on either side of the fault measure the time it takes for a pulse sent toward the fault to be reflected back from the fault. Software combines the timing of the reflection with information on other distribution line characteristics to calculate the distance of the fault from each sensor. The distribution control center can then direct a repair crew to within about one hundred feet of a fault.

Fault Isolation

Another type of Distribution Automation capability aimed at improving reliability is called fault isolation. Many people refer to this capability as "self healing," though this is a bit of a misnomer. Faults must still be repaired ("healed"); fault isolation simply reduces the number of customers impacted by any given fault. Although utilities manually execute fault isolation where the hardware is in place today, Distribution Automation significantly increases the geographic extent and level of automation for fault isolation.

In a Smart Grid, several types of devices on a distribution line can serve to isolate a section of distribution line on which a fault has occurred. These devices, generally called sectionalizing devices, operate automatically by sensing a reduction in electric current. Electric service for customers located within the isolated section will not be restored until the fault is repaired. However, once the section is cordoned off, Distribution Automation reroutes power from a nearby distribution line to customers who lie on the other side of isolated section. Figure 6 shows an initial outage, outage isolation, and immediate service restoration to customers beyond the isolated section.

Figure 6. Representation of fault isolation



Reliability Benefits of Fault Location and Isolation

In Xcel Energy's study of its Boulder, Colorado Smart Grid implementation, findings indicate a total reliability improvement of 22.3 minutes per customer per year from fault location and isolation. Xcel Energy found that fault location reduced the duration of outages by 3.5 minutes per customer per year.[53] The same study finds fault isolation to deliver 28,125 customer minutes of outage reductions annually on each of the two distribution lines with the capability. Assuming an average customer count of 1,500 per distribution line, this capability delivers an additional 18.8 minutes of outage reduction per customer per year.[54]

Translating Reliability Improvements into Indirect Economic Benefits

We estimate the economic productivity impact of outages at $1.80 per minute. (See "Estimating the Economic Productivity Impact of Service Outages" in the appendices for more information.) By multiplying the 22.3-minute outage reduction by avoided economic productivity impact of $1.80 per minute, we estimate $40.14 in indirect economic benefits per customer per year.

Drivers of Fault Location and Isolation Benefits

	Utility Operating Characteristics	Customer Participation and Behavior	Speed of Cost Reduction and Recognition	Market Prices for Electricity and Capacity
Fault Location and Isolation	X			

The more outages a utility has prior to Smart Grid deployment, the greater the reliability improvement that fault location and isolation capabilities are likely to deliver. Reliability benefits are also likely to increase as the number of sensors and sectionalizing devices placed on a distribution line grows.

53 160,000 customer minutes divided by 46,000 customers. Xcel Energy, *SmartGridCity™ Demonstration Project Evaluation Summary* (report to the Colorado Public Utilities Commission), December 14, 2011, 80.

54 Customer counts per distribution line vary widely by utility and within a utility. Anything between 500 and 2,500 customers per distribution line can be considered typical. We chose 1,500 as an estimate. Ibid., 78

Renewable Generation Integration

The degree to which the traditional distribution grid can integrate renewable generation without harm to reliability and efficiency is finite. In this section we will discuss the primary challenges renewable generation presents to grid operators. We will also describe how Smart Meter and Distribution Automation capabilities can help manage the challenges, thereby increasing the amount of renewable generation that can be reliably and efficiently integrated.

	Economic	Reliability	Environmental	Customer Choice
Renewable Generation Integration Benefits	Possible	Likely	Likely	YES

Description and Value Propositions of Renewable Generation Integration

Renewable generation presents two challenges to grid operators. One is the intermittent nature of the most popular types of renewable generation (wind and solar), as they are only productive when the wind is blowing or the sun is shining. Intermittency is an issue with which grid operators must contend regardless of whether renewable generation is centrally located (typically in massive wind farms or solar generating stations that cover thousands or acres) or connected to the distribution grid (for example, PV solar panels mounted on homes). The other challenge relates to the interaction of renewable generation with the distribution grid to which it is attached. The Smart Grid can help address both challenges, with Smart Meters playing a role in intermittency and Distribution Automation helping to reliably and efficiently accommodate customer-sited renewables. We will examine each individually.

Intermittency Challenges

By enabling time-varying rates and customer energy management, Smart Meters allow utilities to engage customers in helping to balance the supply and demand of electricity. When wind and solar generation make up a large portion of a region's generation portfolio, unanticipated changes in wind speed or cloud cover can unexpectedly change electricity supply. Time-varying rates, and particularly dynamic rates that change hourly based on supply and demand, serve to send a price signal to customers about supply and demand.

With dynamic pricing, rates rise in concert with supply reductions or increases in demand and fall in concert with excess supply. Smart Meter–enabled customer energy management systems can work along with dynamic pricing, automatically managing air conditioning and appliance operation within a customer's prespecified instructions as rates rise and fall. This helps provide the flexibility required to reliably accommodate greater levels of renewable generation.

Customer-Sited Generation Technical Challenges

Customer-sited generation, including renewable generation, presents specific technical challenges to distribution grid operators. These issues are readily manageable at low levels relative to a grid's local capacity, but increase in complexity as customer-sited renewable generation levels grow. Customer-sited generation introduces variability that the distribution grid was not designed to handle, reducing grid efficiency and reliability in the process. At higher levels of customer-sited generation saturation, the associated issues include:

- Upstream protective devices (circuit breakers) can trip, causing outages
- Increased variation in voltage and harmonics can degrade power quality
- Increased load and phase variability can make the grid less efficient

Distribution Automation, and a specific set of software and hardware applications generally labeled DERMS (Distributed Energy Resource Management Systems), can help manage the challenges introduced by customer-sited generation. Distribution Automation and DERMS are essential grid investments if high levels of customer-sited renewables are to be accommodated without reductions in grid reliability and efficiency. For more information on these subjects, readers are encouraged to review the section on the challenges of customer-sited generation (renewable and other) in "Technical and Economic Concepts Related to the Smart Grid – A Guide for Consumers," available from the SGCC.

Economic Benefits of Renewable Generation Integration

The economic benefit of accommodating increasing levels of renewable generation is unknown. There are increased costs associated with renewable generation in the short term, including the investments required to accommodate it and the higher capital investment required to build it (per kWh of production relative to natural gas–fired generation[55]). On the other hand, there are economic advantages to renewable generation over the long term, including the avoidance of fuel costs and the potential economic consequences associated with rapid climate disruption.[56] Many researchers have tackled this complex issue and have reached a wide variety of conclusions. As a result, we elect not to quantify the economic benefits of the Smart Grid's capability to integrate greater amounts of renewable generation, but qualify such benefits as "possible."

55 U.S. Energy Information Administration, *Levelized Cost of New Generation Resources in the Annual Energy Outlook 2013,* January, 28, 2013, 4.

56 Electric generation accounts for 33 percent of the carbon dioxide equivalent emissions annually produced in the U.S. U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990–2011,* Table 2-12, April 12, 2013, 2–21.

Reliability Benefits of Renewable Generation Integration

Smart Grid investments are likely needed if significant levels of renewable generation are to be reliably and efficiently integrated into the distribution grid. However, experience with customer-sited renewables at a level which impacts reliability is limited, and we found no research predicting the levels at which customer-sited generation will cause reliability issues. The answer is "it depends," based on a host of variables:[57]

- The strength (impedance) of the distribution line at the point of generation connection
- The specifics of a particular distribution grid's design, operations, and customer loads
- The characteristics of the renewable generation asset (relative size, harmonic output, generation profile, etc.)
- The density/locations/characteristics of other local renewable generation installations

IEEE Standard 1547.2, which governs the connection of customer-sited generation to the distribution grid, suggests that such generation amount to no more than 15 percent of a distribution line's maximum capacity. Utilities in California and Hawaii, the states where customer-sited photovoltaic solar installations are arguably the most common, have moved to a slightly more aggressive standard, allowing up to 100 percent of the minimum load recorded for customers on a distribution line in aggregate.[58] Smart Grid Distribution Automation and DERMS capabilities are likely to improve the amount of renewable generation that can be reliably accommodated on the distribution grid.

Environmental Benefits of Renewable Generation Integration

The greater the level of renewable generation the Smart Grid can reliably and efficiently accommodate, the larger the environmental benefits will be. However, it is difficult to quantify the size of the environmental benefits from Smart Grid capabilities designed to integrate renewable generation due to a host of factors:

- The limits of renewable generation saturation that can be reliably and efficiently accommodated by Smart Grid capabilities have not yet been reached and are unknown.
- The speed with which renewable generation levels will grow varies widely by geography and cannot be accurately predicted.
- The level of investment utilities (and ultimately customers) wish to make in order to reliably and efficiently integrate renewable generation is unknown.

As a result, we elect not to quantify the environmental benefits of the Smart Grid's capability to integrate greater amounts of renewable generation, but qualify such benefits as "likely."

57 Electric Power Research Institute, *Integrating Distributed Resources into Electric Utility Distribution System* (white paper), December 2001, 1–3.

58 Interstate Renewable Energy Council, *Integrated Distribution Planning* (white paper), May 2013, 1.

Customer Choice Benefits of Renewable Generation Integration

As previously discussed, some utilities limit the amount of customer-sited generation on their distribution lines. For example, a 15 percent limit means that the utility will allow up to 750 kilowatts of customer-sited generation to be connected to a distribution line with a peak capacity of 5,000 kilowatts. In 2009, the average size of a residential photovoltaic system was 4 kilowatts.[59] That works out to a limit of 187 systems on this hypothetical distribution line. However, a single photovoltaic solar installation on a large retail store can be as large as 300 kilowatts, significantly restricting the ability of other customers to install their own generation.

By increasing the amount of customer-sited generation the distribution grid can reliably accommodate, Distribution Automation and DERMS enable customers (collectively and individually) to connect greater quantities of renewable generation to a Smart Grid than to a traditional grid. For these reasons, we conclude that these Smart Grid capabilities increase customer choice. It should also be pointed out that the Distribution Automation capabilities that enable greater customer-owned renewable generation also enable greater integration of other types of customer-sited resources tied to the grid, from batteries and fuel cells to combined heat and power plants and microgrids.

Drivers of Renewable Generation Integration Benefits

	Utility Operating Characteristics	Customer Participation and Behavior	Speed of Cost Reduction and Recognition	Market Prices for Electricity and Capacity
Renewable Generation Integration	X	X		X

The largest driver of renewable generation integration benefits is likely to be the willingness of stakeholders to invest today in reliability and efficiency capabilities that, depending on current grid design and customer adoption of renewables, may not be needed until tomorrow. Grid upgrades require long lead times due to size and scale.

Stakeholder conversations on this topic will likely need to address the issue of cost allocation. When Distribution Automation investments are made to accommodate customer-sited renewables, all customers pay for those investments in the form of higher electric rates over time. Similarly, if renewable generation owners avoid paying for their share of the distribution grid, all other customers pay more in the form of higher electric rates over time. These issues are the subject of vigorous debate among distribution utility stakeholders and are outside the scope of this review.

59 Interstate Renewable Energy Council, *2010 Updates and Trends* (annual industry status report), October 11, 2010, 25. (77 percent DC to AC conversion factor applied to 5.2 kW DC figure cited.)

5. COSTS OF THE SMART GRID (AND RELATIONSHIP TO BENEFITS)

Investments must be made to generate the benefits described in this review, and ongoing expenditures must be made to operate and maintain Smart Grid capabilities over time. In this section we describe the likely costs of the Smart Grid.

This section is organized to help readers understand the manner in which we estimated costs as well as the techniques we used to facilitate comparisons of costs to benefits. This section includes:

- Capital investments
- Ongoing expenditures
- Analysis of cost and benefit data

Capital Investments

The U.S. Department of Energy required utilities to submit project budgets for proposed Smart Grid projects to qualify for its Smart Grid Investment Grant (SGIG) matching grant program. These project budgets, including proposed funding from both utilities and SGIG grants, serve as the basis for our Smart Grid cost estimates.[60]

We reviewed summary grant application data to categorize Smart Grid projects as Smart Meter projects or Distribution Automation projects. The total budgeted costs and counts of customers covered by each project were identified and used to calculate a "cost per customer" for each project.[61] We then calculated an average cost per customer for Smart Meter and Distribution Automation projects.

Table 6. Average cost per customer by Smart Grid component

Project Type	Sample Size	Average Cost per Customer
Smart Meter	24 projects	$291.54
Distribution Automation	12 projects	$63.64

There are, of course, some limitations to this analysis. Utilities sometimes exceed their budgets, and changes to project designs and customer counts likely occurred as projects proceeded from planning through design and implementation. However, for the type of secondary research undertaken for this review, this approach is likely the most accurate available to calculate average Smart Grid cost per customer for the most typical Smart Grid deployments.

60 U.S. Department of Energy, "Project Information" and subsequent web pages. Includes summary information on utility projects awarded Smart Grid Investment Grants funded by the American Recovery and Reinvestment Act of 2009. Accessed August 19, 2013.

61 Clear data on customer counts covered by a particular Smart Grid project were not readily available for all projects. Any projects for which customer counts were ambiguous were removed from the analysis. See the appendices for lists of SGIG projects included in the average cost calculations.

Ongoing Expenditures

Ongoing expenditures for asset operation and maintenance are a requirement for large capital investments. After installation, hardware and software must be maintained, repaired, or replaced as needed and operated on a day-to-day basis.

Experience with these sorts of ongoing expenditures in the Smart Grid space is limited as few deployments are fully in place. Once Smart Grid capabilities are fully deployed, no utilities that we know of track associated Smart Grid operations and maintenance expenditures separately; these ongoing costs become part of routine corporate and local operations and maintenance function responsibilities. The U.S. Department of Energy does not track ongoing Smart Grid operations and maintenance expenditures as part of its SGIG program.

To estimate the ongoing expenditures associated with Smart Grid spending, we turn to "rules of thumb" offered by the operations management discipline. Commonly accepted estimates of annual operations and maintenance (O&M) costs range from 2 percent to 4 percent of capital investment.[62] In this review, 4 percent is used as a conservative estimate.

Analysis of Cost and Benefit Data

This review has presented annual economic benefits on a per customer basis. In this section, we present costs for up-front capital investments and ongoing annual operations and maintenance expenditures, again on a per customer basis. Whereas benefits and O&M expenditures are realized over time, capital investments are made up front. To provide an accurate comparison of costs to benefits, we use an analytical framework called "Net Present Value" (NPV).

NPV translates up-front spending, ongoing spending, and ongoing benefits into today's dollars for comparison purposes, adjusting for the time value of money – the idea that a dollar today is worth more than a dollar 10 years from now due to inflation. The time value of money is reflected by the "discount rate," or the rate at which future costs and future benefits are "discounted" to today's dollar values. NPV is an extremely commonplace practice in the business world, and companies – including utilities – regularly use it to help them decide which of many potential investments they are contemplating offers the best economic rewards.

We chose a discount rate reflecting a customer's perspective. In essence, the discount rate represents the interest a customer could earn by purchasing a low-risk investment, such as a government bond, instead of Smart Grid capabilities. Because we are using a 13-year horizon for our cost-benefit analysis, we use the interest rate from a 10-year U.S. government bond (2.74 percent) for the NPV analysis.[63]

62 Harvey Kaiser, *Capital Renewal and Deferred Maintenance Programs,* APPA Body of Knowledge, 2009, 9.

63 U.S. Department of the Treasury Resource Center, "Daily Treasury Yield Curve Rates (Long Term)." Accessed on August 21, 2013.

Tables 7 and 8 indicate how the NPV is calculated for the Reference Case and Ideal Case. Assumptions include:

- Capital costs are evenly split over the first three years of a deployment.
- A three-year ramp-up period is assumed for capabilities requiring customer participation.
- A 10-year post-implementation evaluation period is used to reflect the likely useful life of Smart Grid components.
- Indirect benefits from reliability improvements (service outage management and fault location and isolation) are included, but indirect environmental benefits (that is, the value of carbon emission reductions) are not.

Table 7. Net Present Value calculation for Smart Grid benefits and costs: Reference Case

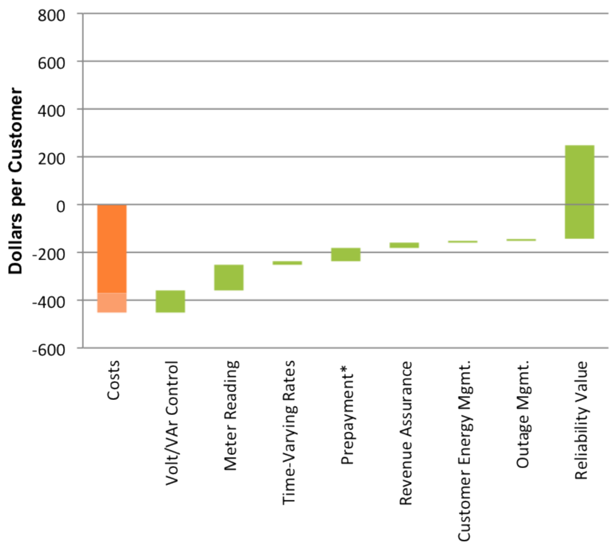
		Deployment Year												
Cost or Benefit Category	**NPV**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
IVVC	89.60				11.24	11.24	11.24	11.24	11.24	11.24	11.24	11.24	11.24	11.24
Meter Reading	109.05				13.68	13.68	13.68	13.68	13.68	13.68	13.68	13.68	13.68	13.68
Time-Varying Rates	14.16				0.66	1.34	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Prepayment	55.38				2.58	5.24	7.82	7.82	7.82	7.82	7.82	7.82	7.82	7.82
Revenue Assurance	23.91				3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Customer Energy Mgmt.	5.45				0.25	0.52	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77
Outage Mgmt (direct)	9.41				1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18
Total Direct Benefits	**306.95**													
Outage Mgmt (indirect)	70.31				8.82	8.82	8.82	8.82	8.82	8.82	8.82	8.82	8.82	8.82
Fault Location & Isolation	319.96				40.14	40.14	40.14	40.14	40.14	40.14	40.14	40.14	40.14	40.14
Total Indirect Benefits	**390.27**													
Smart Meter Costs	-369.22	-97.18	-97.18	-97.18	-11.66	-11.66	-11.66	-11.66	-11.66	-11.66	-11.66	-11.66	-11.66	-11.66
Distribution Automation Costs	-80.60	-21.21	-21.21	-21.21	-2.55	-2.55	-2.55	-2.55	-2.55	-2.55	-2.55	-2.55	-2.55	-2.55
Total Costs	**-449.82**													

Table 8. Net Present Value calculation for Smart Grid benefits and costs: Ideal Case

		Deployment Year												
Cost or Benefit Category	**NPV**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
IVVC	255.16				32.01	32.01	32.01	32.01	32.01	32.01	32.01	32.01	32.01	32.01
Meter Reading	190.67				23.92	23.92	23.92	23.92	23.92	23.92	23.92	23.92	23.92	23.92
Time-Varying Rates	141.49				6.59	13.39	19.98	19.98	19.98	19.98	19.98	19.98	19.98	19.98
Prepayment	138.52				6.45	13.11	19.56	19.56	19.56	19.56	19.56	19.56	19.56	19.56
Revenue Assurance	23.91				3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Customer Energy Mgmt.	13.60				0.63	1.29	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92
Outage Mgmt (direct)	9.41				1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18
Total Direct Benefits	**772.75**													
Outage Mgmt (indirect)	70.31				8.82	8.82	8.82	8.82	8.82	8.82	8.82	8.82	8.82	8.82
Fault Location & Isolation	319.96				40.14	40.14	40.14	40.14	40.14	40.14	40.14	40.14	40.14	40.14
Total Indirect Benefits	**390.27**													
Smart Meter Costs	-369.22	-97.18	-97.18	-97.18	-11.66	-11.66	-11.66	-11.66	-11.66	-11.66	-11.66	-11.66	-11.66	-11.66
Distribution Automation Costs	-80.60	-21.21	-21.21	-21.21	-2.55	-2.55	-2.55	-2.55	-2.55	-2.55	-2.55	-2.55	-2.55	-2.55
Total Costs	**-449.82**													

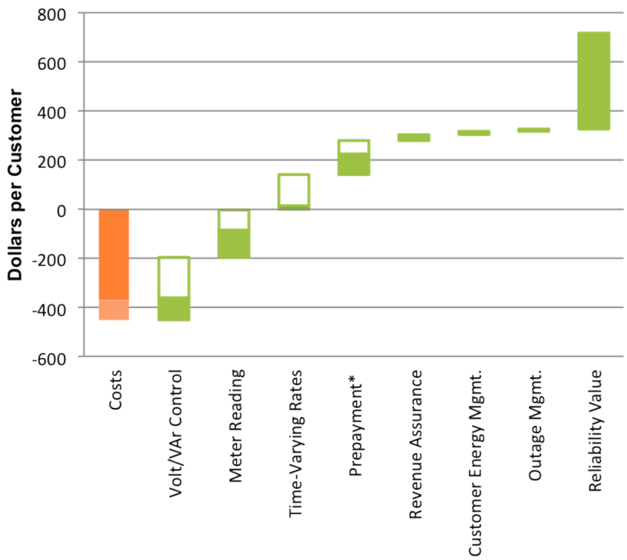
The ratio of benefits (both direct and indirect) to costs is 1.5 to 1 in the Reference Case[64] and 2.6 to 1 in the Ideal Case.[65] These results are depicted graphically by Smart Grid capability in the following figures.

Figure 7. Smart Grid costs and benefits per customer: Reference Case



* Includes remote disconnect and reconnect benefits

Figure 8. Smart Grid costs and benefits per customer: Ideal Case



* Includes remote disconnect and reconnect benefits

Open boxes represent the difference in benefit from the Reference Case to the Ideal Case.

64 Reference Case benefits to cost ratio = ($306.95 + $390.27)/$449.82 = 1.5 (to 1).

65 Ideal Case benefits to cost ratio = ($772.75+$390.27)/$449.82 = 2.6 (to 1).

6. CONCLUSIONS AND RECOMMENDATIONS

In reviewing and synthesizing research on the actual benefits and costs of Smart Grid capabilities and investments, the SGCC intended to provide stakeholders with new insights into the current and potential value of grid modernization and identify associated drivers of that value. While we believe this review has accomplished these objectives, we are struck by the increasingly critical role electric distribution grids will play in the future economic vitality, productivity, and sustainability of the communities they serve. As a result, we have come to see this work as an opportunity to chart a new course in the manner in which stakeholders collaborate to establish and execute a common vision for the distribution grids that serve them. In addition to summarizing our findings, drivers, and opportunities, this section also includes recommendations for researchers and stakeholders.

Findings

We find that the Smart Grid offers a favorable benefit-to-cost ratio when considering both direct and indirect economic benefits. Based on available research and incorporating the conservative Reference Case assumptions detailed in this report, the ratio of direct and indirect benefits to costs is 1.5 to 1.[66] Using the Ideal Case assumptions detailed in this report, the ratio of direct and indirect benefits to costs is 2.6 to 1.[67] In both cases, the indirect benefit from service reliability improvements is significant – and significantly reduces customer inconvenience, as well.

We also find that the Smart Grid offers significant reductions in environmental impact, including both quantifiable and nonquantifiable benefits. Quantified environmental impact reductions of almost 600 pounds of carbon dioxide equivalent emissions per customer per year are available in the Ideal Case from the conservation impact offered by Smart Grid capabilities such as Integrated Volt/VAr Control and time-varying rates. Smart Grid capabilities also appear to enable greater amounts of renewable generation to be integrated by addressing associated intermittency and technical challenges. Although difficult to quantify, the environmental impact reductions from greater amounts of renewable generation are likely many multiples higher than the quantified amounts from Smart Grid capability conservation effects.

Finally, by enabling adoption of new products and services, Smart Grid investments can serve to greatly increase customer choice.

These findings are based on critical assumptions about customer participation levels, utility operating and market characteristics pre- and post-investment, and the speed with which operating cost reductions are effected and recognized.

66 Reference Case benefits to cost ratio = (\$306.95 + \$390.27)/\$449.82 = 1.5 (to 1).

67 Ideal Case benefits to cost ratio = (\$772.75+\$390.27)/\$449.82 = 2.6 (to 1).

Benefit Drivers

Although utilities execute many Smart Grid capabilities "behind the scenes," many other capabilities require extensive and active customer engagement in order to maximize benefits. Customer participation level is the single largest benefit driver for many capabilities that Smart Meters facilitate, including time-varying rates, prepayment programs, and customer energy management. The SGCC encourages utilities to take advantage of the resources and best practices we offer to help engage customers and maximize the benefits from these Smart Grid capabilities.

Another set of drivers involves utility operating characteristics pre- and post-investment, including the variables of electric energy and capacity costs specific to each geography. As examples of the former, utilities with automated meter reading pre-deployment are not likely to secure as much meter-reading cost reduction from the installation of Smart Meters as utilities with manual meter reading. Post-deployment, utilities can choose the extent to which they prioritize and utilize certain Distribution Automation capabilities such as Integrated Volt/VAr Control. As examples of the latter, geographies with higher-than-average electric energy and capacity costs are likely to see greater Smart Grid benefit-to-cost ratios relative to geographies with lower-than-average energy and capacity costs.

Another important variable is the speed with which a utility can begin realizing – and passing on to customers – cost savings from Smart Grid investments. Large Smart Grid deployments are enormous logistical undertakings that can take years to complete. It is not hard to imagine how the first Smart Grid investments a utility makes might require six years to begin paying off for customers – two to three years in field deployment; another year or so in software, process, and customer program development and employee training; and another few years to reach target customer participation levels.

Finally, regulatory rules and norms that can inhibit customer economic benefits exist in many states. For utilities that do business under traditional ratemaking practices, it is important to address the risk that lower sales volumes brought about by Smart Grid–enabled capabilities hinder utilities' ability to recover costs. Several potential solutions to this issue include, but are not limited to, the following:

- Incorporating anticipated sales volume reductions from Smart Grid capabilities into the ratemaking process
- Allowing investor-owned utilities to earn an incentive to maximize Smart Grid–related sales volume reductions in a manner similar to that for demand-side management programs
- Continuing dialog about how to improve traditional ratemaking to better address benefits that require sales volume reductions

Additional regulatory factors, such as those around billing and payment programs, may need to be addressed by stakeholders as various Smart Grid capabilities are deployed. The SGCC hopes this review will help to enable further dialogue and collaboration among stakeholders.

Recommendations for Researchers

This review indicates that the Smart Grid has opened up entire fields of research opportunities. Those that appeared to be priorities to us as we completed this review are summarized below.

Customer Engagement

The SGCC is at the forefront of research related to consumers' perceptions and attitudes toward electricity. This review confirms that our focus on this issue is well placed, and we encourage others to join us as we prioritize new efforts:

- What economic, environmental, and community benefit messages engage customers and raise program participation?
- What role can peer influences play in awareness, participation, and behavior change?
- What new products (such as free weekends) and services (such as outage information messages) made possible by the Smart Grid are of greatest interest to customers?

Identification and Communication of Best Practices

Because distribution utilities do not compete against one another, they have a unique opportunity to widely and openly share best practices. Our research indicates that there are several areas that would benefit from increased best practice dissemination among distribution utilities:

- What new uses are utilities finding for Smart Meter and Distribution Automation data?
- What are the best ways to measure Smart Grid benefits and impacts?
- How are stakeholders working to optimize the value drivers described in this review?

Renewable Generation Integration

There is a dearth of information about the integration of customer-sited and renewable generation. Questions for future research include:

- How much customer-sited generation can a traditional grid reliably and efficiently accommodate?
- How much additional customer-sited generation can Distribution Automation capabilities such as DERMs help accommodate?
- What are the economic, reliability, environmental, and customer choice benefits of this increase relative to costs?
- What are the limits and drivers of customer response to notices or price signals?

Recommendations for Stakeholders

The research presented in this review indicates that grid modernization can create direct economic benefit for customers in excess of costs. This review also indicates that significant indirect benefits – primarily from reliability improvements but also from reduced environmental impact – are available to society at large. This review also makes clear that multiple drivers, including those with significant inherent complexity, can considerably impact the level of benefit customers receive from Smart Grid investments.

The SGCC encourages all stakeholders (utilities, regulators, advocates, customers, and legislators) to prioritize collaboration in pursuit of workable solutions to increase customer participation, speed benefit recognition, and address regulatory opportunities.

7. APPENDICES

Reference Case and Ideal Case Benefit Assumptions

Utilities are not likely to experience the same benefits presented in the Reference Case or Ideal Case, as each utility's operating characteristics and market conditions are likely to differ from the assumptions presented in this report. To help report users adjust for specific situations, the primary benefit drivers are listed below along with the assumptions used to create the Reference Case and Ideal Case. Sources for assumptions are footnoted throughout the review.

Table 9. Reference Case and Ideal Case benefit assumptions

Capability	Primary Benefit Drivers	Reference Case Assumptions	Ideal Case Assumptions
Integrated Volt/VAr Control	• Average reduction in peak demand • Average reduction in energy use	• 3.5% peak reduction • n/a	• 3.5% peak reduction • 2.7% energy reduction
Remote Meter Reading	• Type of meter reading (manual or automated) prior to Smart Meter rollout • Policy regarding move ins/move outs (is prorating allowed between meter reads or must meters be read on customer move dates?)	• Routine monthly meter reads previously automated • Prorating prohibited	• Meter reading previously manual • Prorating prohibited
Time-Varying Rates	• Customer participation rates (opt in) • Customer response level to price differentials • Conservation impact • Average peak demand per residential customer • Value of generation capacity avoided • Average usage per residential customer per year • Value of electricity use avoided	• 2% participation • 20% load shift • 4% usage reduction • 2.575 kW/customer (1) • $134.28/kW year (1) • 11,280 kWh/year (1) • $0.0682/kWh (1)	• 20% participation • 20% load shift • 4% usage reduction • 2.575 kW/customer (1) • $134.28/kW year (1) • 11,280 kWh/year (1) • $0.0682/kWh (1)

Prepay and remote disconnect/ reconnect	• Customer participation rates • Conservation impact • Existence of remote disconnect prohibitions	• 2.5% participation • 11% usage reduction • No remote disconnect prohibitions	• 5% participation • 11% usage reduction • No remote disconnect prohibitions
Revenue Assurance	• Level of electricity theft prior to Smart Meter deployment • Average age of meters being replaced		
Customer Energy Management	• Customer participation rates • Feedback mechanism type • Conservation impact	• 2% participation • In-home display • 5% usage reduction	• 5% participation • In-home display • 5% usage reduction
Service Outage Management; Fault Location and Isolation	• Value assigned to a minute of reliability improvement	• $1.80/minute (weighted average opportunity cost to residential, commercial, industrial)	• $1.80/minute (weighted average opportunity cost to residential, commercial, industrial)
Renewable Generation Integration	• Difference in cost of relative to central resources • Difference in environmental impact vs. central • Value of environmental impact reductions • Ratio of customer-sited to central resources over time		

(1) These assumptions are used throughout the report as appropriate.

Calculation of Benefits

Table 10. Benefit driver assumptions for calculations

Variable	Assumption	Value
A	Average energy use per U.S. residential electric customer per year[68]	11,280 kWh
B	Average peak demand per U.S. residential electric customer[69]	2.575 kW
C	The variable cost of electricity per kWh[70]	$0.0682
D	The value of generation investments delayed or avoided per unit of demand reduced[71]	$134.28 per kW yr.
E	CO_2 equivalent emissions (lbs.) per kWh[72]	1.22
F	Percentage reduction in peak demand from IVVC	3.25%
G	The amount of electric use reduced per year from IVVC	2.7%
H_r	Assumed participation rate in time-varying rates, Reference Case	2%
H_i	Assumed participation rate in time-varying rates, Ideal Case[73]	20%
I	The amount of demand reduced at a point in time from "shifting" by customers participating in time-varying rates	20%
J	The amount of electric use reduced per year among those participating in time-varying rates[74]	4%
K	The amount of electric use reduced per year among those participating in prepayment programs	11%
L_r	Assumed participation rate in prepayment programs, Reference Case	2%
L_i	Assumed participation rate in prepayment programs, Ideal Case	5%
M	Billing and collection expense reduction per prepayment customer	$300

68 U.S. Energy Information Administration, *2011 Annual Electric Power Industry Report* (File 2, Electric sales, revenue, and average price, Column W, total consumers), April 2012.

69 Calculated based on 11,280 kWh per year for an average U.S. residential electric customer assuming a 50 percent capacity factor. Peak demand = (average demand/8,760 hours annually)/capacity factor.

70 U.S. Energy Information Administration, "Table 5.3. Average Retail Price of Electricity to Ultimate Consumers" (Line 14, 2011, Column D, Industrial), September 20, 2013.

71 Kathleen Spees, *Cost of New Entry Estimates for Combustion Turbine and Combined-Cycle Plants in PJM,* The Brattlle Group, August 24, 2011. Page 2, Table 1, final column average (PJM 2014/15 CT CONE).

72 U.S. Environmental Protection Agency, *eGRID 2012 Subregion GHG Output Emission Rates for Year 2009,* April 2012. Summary table 1, column = total output emissions rate (lb/MWh). http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2012V1_0_year09_SummaryTables.pdf.

73 Testimony of J. Richard Hornby to the Arkansas PSC in Docket 10-109-U, Exhibit JRH-4, page 2, May 20, 2011. "OG&E assumes 20 percent of residential customers will voluntarily enroll in its VPP rates."

74 Chris King and Dan Delurey, "Efficiency and Demand Response: Twins, Siblings, or Cousins?" *Public Utilities Fortnightly,* March 2005, 55.

N	Average monthly bill per prepayment customer[75]	$110
O	Average days' sales outstanding[76]	53
P	Utility weighted average cost of capital (daily)[77]	0.0095%
Q	Bills per year	12
R	The amount of electric use reduced per year among those utilizing an in-home display (conservative end of the range found in research)	5%
S_r	Assumed participation rate in home energy management, Reference Case	2%
S_i	Assumed participation rate in home energy management, Ideal Case	5%

Table 11. Benefit calculations for Reference Case and Ideal Case

Capability	Calculation	Reference Case Value	Ideal Case Value
Integrated Volt/VAr Control peak demand reduction	B x D x F	$11.24	$11.24
Integrated Volt/VAr Control conservation benefit	A x C x G	N/A	$20.77
Integrated Volt/VAr Control CO_2e reduction	A x E x G	Likely	372 lbs.
Time-varying rate peak demand reduction	B x D x H x I	$1.38	$13.83
Time-varying rate conservation benefit	A x C x H x J	$0.62	$6.15
Time-varying rate CO_2e reduction	A x E x H x J	11 lbs.	110 lbs.
Prepayment program conservation benefit	A x C x K x L	$1.69	$4.23
Prepayment program conservation benefit per participant	A x C x K	$84.62	
Prepayment program billing, collection and interest reduction benefit	[M + (N x O x P x Q)] x L	$6.13	$15.33
Prepayment program CO_2e reduction	A x E x K x L	30 lbs.	76 lbs.
Customer energy management benefit	A x C x R x S	$0.77	$1.92
Customer energy management CO_2e reduction	A x E x R x S	14 lbs.	34 lbs.

75 U.S. Energy Information Administration, "Table 5A. Residential Average Monthly Bill by Census Division, and State 2011." Table 5_a, Line 66 (U.S. total), Column C ("Average Monthly Consumption").

76 Top-quartile (better than 75 percent) utilities. *Cash on the Meter* (white paper), Ernst & Young, May 2009, 6.

77 3.47 percent divided by 365 days. Aswath Damodaran, "Cost of Capital by Sector," January 2013. Analysis of 6,177 firms in the Value Line dataset; "Electric Utility (Central)."

Estimating the Economic Productivity Impact of Service Outages

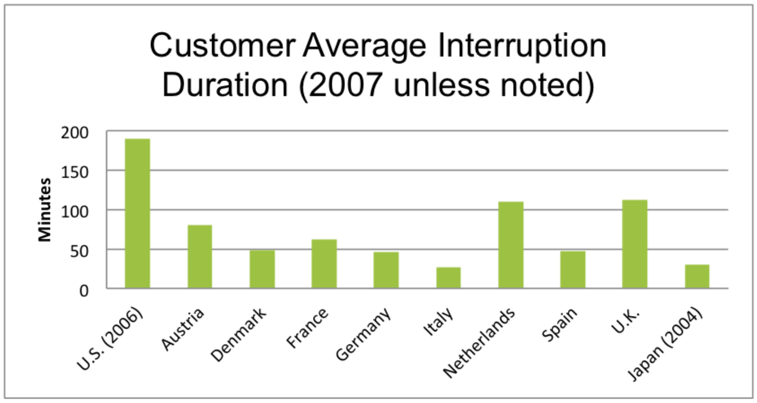
The cost to the U.S. economy of electric service outages is estimated in many studies. All the studies estimate large impacts on productivity – between $30 billion and $400 billion per year.[78] One of the better controlled and more often cited studies (conducted by Primen for EPRI) estimates the cost of power outages in the U.S. at between $104 billion and $164 billion a year.[79] A more relevant and more recent Lawrence Berkeley National Laboratory study estimates the opportunity cost at $80 billion annually.[80]

The high productivity costs of service outages stems from several sources:[81]

- Lost business sales
- Spoiled production runs
- Spoiled experiments
- Spoiled food
- Property damage (from failed protection systems)
- Associated health and medical issues

The U.S. economy competes with those of other nations. Issues inhibiting the productivity of the U.S. economy, including electric reliability, are a source of concern to lawmakers at the state and federal levels. A comparison of U.S. reliability indicating an opportunity for improvement follows. Research indicates the Smart Grid can significantly improve U.S. service outage performance.

Figure 9. Representative customer average interruption duration indices by nation[82]



78 Greg Rouse and John Kelly, *Electric Reliability: Problems, Progress, and Policy Solutions* (white paper), Galvin Electricity Initiative (now the Perfect Power Institute), February 2011, 4.

79 Electric Power Research Institute, *The Cost of Power Disturbances to Industrial and Digital Economy Companies* (study conducted by Primen), June 29, 2001, ES-3.

80 Kristina Hamachi LaCommare and Joseph H. Eto, *Understanding the Cost of Power Interruptions to U.S. Electricity Consumers,* Lawrence Berkeley National Laboratory (for the U.S. Department of Energy), September 2004, 41.

81 Greg Rouse and John Kelly, *Electric Reliability: Problems, Progress, and Policy Solutions* (white paper), Galvin Electricity Initiative (now the Perfect Power Institute), February 2011, 4.

82 U.S. Source: Joseph H. Eto and Kristina Hamachi LaCommare, *Tracking the Reliability of the U.S. Electric Power System,* Lawrence Berkeley National Laboratory (for the U.S. Department of Energy), October 2008, 25. EU source: Council of European Energy Regulators, *4th Benchmarking Report on the Quality of Electric Supply,* 2008. Japan source: Masanori Kondo, "Activities of the Japan Electricity Task Force for the India Market" (presentation), March 9, 2007, 14.

Translating Reliability Improvements into Indirect Economic Benefits

Using the Lawrence Berkeley National Laboratory's estimate of $80 billion annually in service outage costs as a basis, we attempt to estimate the indirect economic benefits available from service outage reductions delivered by the Smart Grid. Dividing the LBNL estimate by the number of U.S. electric customers estimated by the Energy Information Administration (151.7 million),[83] we estimate an economic productivity impact equal to $527.35 per customer per year from service outages. By applying the U.S. System Average Interruption Duration Index of 292 minutes,[84] we arrive at an estimated economic productivity impact per minute of outage per customer of $1.80.

Commercial and Industrial customers who have more at stake are more interested in improving reliability than the average residential customer, who is more likely to be content with the average 99.95 percent uptime the average U.S. customer experiences.[85] The SGCC encourages stakeholders to consider the future – with increased customer reliance on electricity, increased likelihood of extreme weather events, and the increased reliability challenges likely to be imposed on the grid by electric vehicles and customer-owned generation – when assessing the value of investments in reliability-related Smart Grid capabilities.

83 U.S. Energy Information Administration, *2011 Annual Electric Power Industry Report* (File 2, Electric sales, revenue, and average price, Column W, total consumers), April 2012.

84 Joseph H. Eto and Kristina Hamachi LaCommare, *Tracking the Reliability of the U.S. Electric Power System,* Lawrence Berkeley National Laboratory (for the U.S. Department of Energy), October 2008, 25.

85 Greg Rouse and John Kelly, *Electric Reliability: Problems, Progress, and Policy Solutions* (white paper), Galvin Electricity Initiative (now the Perfect Power Institute), February 2011, iii.

SGIG Projects Used to Estimate Costs per Customer

Smart Meter Projects

- Baltimore Gas & Electric (MD)
- Central Maine Power (ME)
- Salt River Project #1 (AZ)
- Salt River Project #2 (AZ)
- Cleco Power (LA)
- South Mississippi Electric Power Association
- Lakeland Electric (FL)
- Denton County Electric Co-op (TX)
- Cobb Electric Co-op (GA)
- South Kentucky Rural Electric Co-op
- Talquin Electric Co-op (FL)
- Black Hills Electric Utility (CO)
- Black Hills Power (SD)
- Cheyenne Light Fuel & Power Company (WY)
- Entergy New Orleans (LA)
- Navajo Tribal Utility Association (AZ)
- Sioux Valley Southwestern Electric Co-op (SD)
- Woodruff Electric (AR)
- Allete Inc. (Minnesota Power)
- City of Fulton (MO)
- Marblehead Municipal Light Dept. (MA)
- Tri State Electric Membership Co-op (GA)
- Wellsboro Electric Co-op (PA)
- Stanton County Public Power District (NE)

Distribution Automation Projects

- Consolidated Edison Company of NY (NY)
- Avista Utilities (ID)
- PPL Electric Utility Corp. (PA)
- Atlantic City Electric Company (NJ)
- Snohomish County Public Utility District (WA)
- NSTAR Electric Co. (MA)
- Hawaiian Electric Company (HI)
- Memphis Light Gas & Water Division (TN)
- Northern Virginia Electric Co-op (VA)
- Wisconsin Power & Light (WI)
- Powder River Energy Corp. (WY)
- El Paso Electric (TX)

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