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This World Economic Forum report was developed by the Forum's Energy Industry Partnership in collaboration with Accenture and with the input from an Advisory Board of experts.

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The views expressed in this publication do not necessarily reflect those of the World Economic Forum, Accenture, the Smart Grid Advisory Board members or the Industry Partner companies.

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Accelerating Smart Grid Investments – Executive Summary

The challenges of climate change and the continued growth of electricity demand are putting increasing stress on the world's electricity network infrastructure. The prevailing design philosophy for the existing electricity networks is a legacy from a period when energy was relatively cheap and plentiful and meeting rising demand was the dominant driver. The world is now at the point of transition to a new era where clean energy will be at a premium, networks will need to be flexible to the incorporation of new low-carbon technologies and customers will demand greater insight and control over their own consumption.

Smart grids are a necessary element to enable this transition:

- They deliver energy more efficiently and reliably
- They provide the capacity to integrate more renewable energy into existing networks
- They provide the ability to manage increasing numbers of electric vehicles
- They enable customers to have greater control of their energy
- They have considerable capacity to reduce global carbon emissions
- They stimulate an array of new business models in the energy sector

In addition to noting the benefits, it is worth recognizing the potential impact of inaction: without smart energy infrastructure, the integration of intermittent renewable energy supply and the charging requirements for electric vehicles have the potential to put the stability of the energy system at risk. Even at relatively low penetration levels, these technologies could cause instability and increased risk of outages. By acting now, decision-makers can avoid having the electricity infrastructure become a bottleneck to delivering a lower-carbon future.

“Smart grids are emerging as the next strategic challenge for the energy sector and as a key catalyst to achieve the vision of a low-carbon economy.”

Ignacio S. Galán, Chairman and Chief Executive Officer, Iberdrola, Spain

Smart grid technology will bring together the advancements in the IT and Telecommunications sector – embedded sensing, computing and ubiquitous communications – to deliver a safer, more efficient and more resilient energy system. Not dissimilar to the Internet, this smart grid will act as a backbone infrastructure, enabling a suite of new business models, new energy management services and new energy tariff structures. The smart grid will enhance the way that utility companies manage assets and offer consumer-relevant products and services, how consumers interact with their energy supply, and how governments respond to the challenge of maintaining security of supply and reducing carbon levels

while managing costs of energy delivery. However, a number of factors are holding back this transition and may ultimately act as a limiting factor to the broader drive to reduce greenhouse gas emissions. This paper seeks to define smart grids and present a recommended design philosophy, identify the barriers to adoption and, finally, suggest potential strategies to address the challenges.

One Size Does Not Fit All

The transition towards a smart grid can be driven by a number of factors, some or all of which may apply to varying degrees. However, the hierarchy of needs will vary from country to country, region to region and even circuit to circuit, based on the legacy network that exists and the ambitions of local policy-makers. In some cases, reliability may dominate the list of outcomes due to challenges faced by an ageing infrastructure; however, in another area, the drive to incorporate plug-in hybrid electric vehicles and distributed generation and storage may be dominant. In these instances, different physical architectures might evolve that are optimized to the local need. Over time, needs may change and therefore the design philosophy will need to embrace the concepts of flexibility, modularity, scalability and forward compatibility.

“Ultimately, smart grids empower consumers by providing unprecedented visibility and control over energy usage and will change the way we all think about and buy energy. This new system will also transform the relationship between the utility and consumer from a one-way transaction into a collaborative relationship that benefits both, as well as the environment.”

Peter L. Corsell, Chief Executive Officer, GridPoint

To highlight the issue of variability in vision and design, a number of smart grid archetypes have been outlined to highlight how changes in the hierarchy of needs may lead to smart grids that are optimized to prioritize certain functionality. These are not intended as a menu of designs, but simply as a demonstration of their potential diversity. In each case, policy-makers and regulators will need to define their hierarchy of needs and then work with the incumbent utility to define the journey that takes them from where they currently are to where they want to be. In each case, the transition will need to be defined to allow a gradual layering of capabilities that will lower the impact on the incumbent utility and deliver the best value for the customer.

Policy and Framework Alignment

There are a number of factors that, in combination, act as a brake on smart grid investment, most of which are institutional and relate to the regulatory and policy frameworks that have evolved to support the existing power delivery system. The current frameworks often create reverse incentives or fail to create sufficient positive incentives for private sector investment. In the future, the regulatory model will have to adapt to balance a suite of outcomes in which carbon reduction and security of supply are rewarded in the same way that productivity and efficiency gains have been rewarded in the post-privatization era. As a consequence, difficult trade-offs may need to be made with the degree of market competition and cost to the consumer.

“Smart grids represent an evolution of the electricity network from generation to consumption in a way that is interactive, flexible and efficient. The challenges include integrating renewable but intermittent power from large-scale plants, often located far from consumers, and from small-scale installations. It will take several decades to apply the solutions to a mix of new and existing equipment. All stakeholders – policy-makers, regulators, utilities and vendors – must tackle this challenge together.”

Joe Hogan, Chief Executive Officer, ABB

If policy-makers and regulators see long-term carbon reduction and security of supply as important outcomes, they will need to rebalance the regulatory incentives to encourage privately financed utilities to invest at rates of return that are commensurate with the risk that they are taking. The relative risk profile for smart grid investments, given the technology and delivery risks that come with relatively immature suite technologies, will require policy and regulatory frameworks that allocate risk to the parties that can diversify it most effectively. This may mean creating frameworks that allow risk to be shared between customers (either through their utility bills or taxes) and shareholders so that risks and rewards are balanced at the lowest total cost to the customer. As it stands, there are few examples of where this is being done effectively.

Moving from a Utility-centric Business Case to a Broader Societal Value Proposition

In those cases where more forward-thinking regulators and policy-makers have either commissioned business cases or progressive utilities have taken it upon themselves to push the issue, there have been mixed results. Typically, the smart grid business case is tackled as an add-on to the AMI business case and, as a stand-alone case, it is hard to justify the additional expenditure. In the majority of cases, there have been negative business cases driven by two fundamental challenges:

- **High capital and operating costs** – Capital and operating costs include large fixed costs attributable to the ubiquitous communications network; hardware costs do not factor in significant improvements in economies of scale and production innovation, and software integration assumes significant delivery and integration risks.
- **Benefits are constrained by regulatory rules** – When assessing the benefits business case, modellers are restricted in what they can realize as cash benefits to the shareholder. For example, in many cases, line losses are considered as a pass-through to the customer and, therefore, any reduction in losses would have no net impact on the utility shareholder.

There is a clear link between the business case and many of the barriers identified in this section. Regulatory and policy frameworks determine the economics of the business and therefore drive what can be accounted for in the benefits case. They determine what benefits can be monetized and which remain neutral to the utility shareholder despite being of potentially significant value to the consumer or society more broadly. Governments and industry need to jointly assess the value for smart grid investment and to develop either convincing rate cases that reflect the value of the positive externalities, or public-private partnership vehicles to share the investment burden between the public and private purse. By moving beyond the traditional utility-centric business case to a broader view of the societal value, it will make it easier for politicians and regulators to articulate the value to customers.

In the early years of smart grid investment, the costs will inevitably reflect the relatively high risk of cost overruns. By investing in a small number of high profile, large-scale, integrated pilots and sharing the learnings, the global smart grid community will be able to reduce the risk premium on the capital and operating costs to a level that makes the value case more viable. With US\$ 461 million of total smart grid investment in 2008 and an expected significant increase in investment requirements over the coming decade,¹ even small percentage reductions have a large impact.

Cities as Catalysts

During the early stages of the transition towards smart grids, cities will play a critical role in demonstrating the art of the possible and consequently reducing the delivery risk for regional or national roll-outs. Cities such as Boulder, Colorado, and Austin, Texas, are already leading the way with large-scale pilots, and this trend can be expected to continue with a migration to larger and larger cities. However, not every city is suitable to be at the vanguard of this change. To identify those cities that are most likely to lead the change, a number of factors must be identified that, when they converge, will produce an environment that is primed for change. Key considerations include the market structure (i.e. regulated or liberalized), the degree of political alignment at the city level and the occurrence of municipal asset ownership.

Conclusion

Despite the clear benefits case for smarter electricity infrastructure, there are a number of factors, as defined within this report, which are acting as a brake on investment.

Two key themes sit at the heart of overcoming such challenges:

- **Regulatory refresh** – There is an urgent need to refresh the utility regulatory regimes that oversee the governance and economics of the power industry. No longer is it the sole purpose of this industry to provide energy to the masses at cost-competitive prices; there now exists a set of competing imperatives which centre on the provision of infrastructure to support a low-carbon economy while maintaining security of supply and quality of service to the end consumer. The regulatory regimes worldwide need to be restructured to reflect these new imperatives. Governments and regulators should provide clear profit motives to utilities to place value on energy efficiency, encouraging utilities to produce and deliver as efficiently and clean electricity as possible, without compromising security of supply. In both vertically integrated and competitive utility value chains, utilities should be rewarded for helping achieve this mission.
- **Public-private partnerships and societal value propositions** – The limitations need to be recognized of either the utility or the city/region acting in isolation. A wealth of smart grid benefits sit across the boundary between the utility and society as a whole. It is unrealistic to expect the utility shareholder to take on the full risk of investment in this instance. Public-private partnerships are required for this technology to reach its full potential. A new era of collaboration is essential.

It is necessary to move away from purely financial business cases to develop broader societal value propositions, which are reflective of more than financial benefits and consider positive effects on citizens and businesses from clean, reliable energy supply. They can then be used as a tool with which to appropriately allocate smart grid cost/benefit.

Smart Grids as an Enabler to the Low-Carbon Economy

The development of a fully fledged, low-carbon economy will require changes to the core electricity infrastructure. Smart technologies will be a necessary element of this transformation.

Over the next two decades, assuming a limited intervention scenario, the International Energy Agency (IEA) expects to see aggregate global energy demand to roughly double from current levels as the population increases, new consumers in the developing world acquire electronic products and the growth in computing consumption increases.² This growth in demand will coincide with a global drive towards lower carbon generation sources in the battle with climate change. It will also operate within the context of an ageing power grid transmission and distribution infrastructure which desperately requires investment.

To successfully transition to a fully fledged low-carbon economy, the core infrastructure for transmission and distribution of electricity needs to be addressed. Smart technologies will be a necessary part of this transformation, applying telecommunications and computing technologies developed over the last two decades to the current and future electricity infrastructure.

Cities will play an important role in managing this transition. At present, 71% of the world's carbon emissions are from urban centres³ and, as such, cities are at the front line of the battle for a low-carbon economy. Cities are at the centre of global commerce, industry and finance, and are critical to the functioning of the global economy. If urban environments are to be sustainable in the long-term, it will be critical to develop scalable, secure and reliable communications and power grid networks that will become the backbone for a much broader suite of advanced and low-carbon technologies. Cities, as centres of consumption, will become the focus for energy conservation and efficiency, and smart technologies will enable new products and services to be offered to help consumers manage energy needs, whether at home, at work or in transit.

The US Department of Energy published their Grid 2030 vision in July 2003 in which they stated the intention to migrate towards smart grids. However, over the six years since its publication, progress towards the vision has been hampered by misalignment of incentives among customers, government, regulators, utilities and product suppliers. Standard business case methods often fail to represent the true cost/benefit of smart grid investments; costs are high, driven partially by a lack of awareness

regarding the opportunities for realizing economies of scale and scope within infrastructure investments to deliver multiple outcomes, and do not represent the full spectrum of hard and soft benefits, many of which cannot be ascribed a specific monetary value. It is possible to move beyond this impasse by creating a suite of policy and economic frameworks that allow the alignment of incentives across stakeholders and define value cases that more fully describe the benefits case at a societal level.

The global and local response to the challenges of climate change will require an integrated supply- and demand-side response. On the supply side, there is a drive towards sustainable, low-carbon electricity generation (e.g. nuclear, wind power, solar, etc.) and hydrocarbon substitution (e.g. biofuels, biogas, electric vehicles, etc.). On the demand side, customers are increasingly seeking more information and control over their consumption and, as a consequence, there are new technologies that enable energy conservation and efficiency (e.g. smart buildings, smart meters, demand response, etc.). Without investment in the smart grid infrastructure to support these technologies, natural limits will be reached as to what can be achieved. The existing distribution grid infrastructure is primarily designed for one-way flow of electricity and limited consumption in the home. With the growing implementation of large-scale, intermittent renewable energy generation, distributed generation and electric vehicles, the operational limits of the network as it is currently designed will be reached. To avoid stalling progress towards a sustainable and low-carbon future, necessary investments must be made in power grid and urban infrastructures that will effectively (without significant operational constraints) accommodate these technologies at large-scale deployment.

1. What Defines a Smart Grid and Why Do We Need Them?

1.1 Introduction

In the following section we will describe the power grid, how it operates today and how a smarter grid will change the design and operations to lead to more efficient, effective power delivery in the future. There are several challenges which are leading decision-makers to consider this technology as an option and in some cases a requirement. This section will explore the different capabilities which sit within the smart grid construct and how they help respond to those challenges. Once it is recognized that smart grids are not a simplistic one-size-fits-all, it is possible to examine the geographic variances which occur and identify several smart grid archetypes which correspond to a location's specific starting point and implementation objectives.

1.2 How Does the Power Grid Operate Today?

Today's power grid is analogue and needs a great deal of investment. There is significant scope for operational improvements through smart grid technologies.

Today's power grid is composed of two networks. The first is an actively managed transmission network which supplies electricity over longer distances at a higher voltage; the other, the distribution network, operates at a lower voltage and takes electricity the last mile to individual homes and businesses. Combined, transmission and distribution networks represent a significant technical legacy, mirrored in its investment requirements; current estimates are US\$ 13 trillion worldwide through to 2030.⁴

"He's been dead more than 75 years, but Thomas Edison – hailed as the father of the light bulb – probably could run the nation's modern-day electric grid. It just hasn't changed that much."⁵

Unlike other industries, telecommunications for example, power utility infrastructure is composed of many analogue/electromechanical legacy systems that are prone to failure and blackouts. It is dominated by centralized generation disseminated via a relatively passive (limited control), and one-way or limited two-way communication network between utilities and the end users. Residential energy consumption is often projected rather than measured. Grid maintenance is time-based and often reinforced when system components fail or reach their expected lifetime. Outage management practice relies on consumers notifying the utility that a power outage has occurred. A significant volume of the electricity which enters the network is lost either through technical inefficiencies or theft from 4-10% in Europe⁶ to more than 50% in some developing city environments.⁷

Figure 1: Transition to a smart grid

Current State	Modern Utility
Analogue/electromechanical	Digital/microprocessor
Centralized (generators)	Decentralized (generation)
Reactive (prone to failures and blackouts)	Proactive
Manual (field restoration)	Semi-automated, automated (self-healing)
One price	Real time pricing
No/limited consumer choice	Multiple consumer products
One-way communication (if any)	Two-way/integrated communication
Few sensors	Ubiquitous monitors, sensors
Manual restoration	Condition-/performance-based maintenance
Limited transparency with customers and regulators	Transparency with customers and regulators
Limited control over power flows	Pervasive control systems
Estimated reliability	Predictive reliability

1.3 What Is a Smart Grid?

Smart grids incorporate embedded computer processing capability and two-way communications to the current electricity infrastructure. Smart grids operate across the utility value chain, and should not be confused with smart meters.

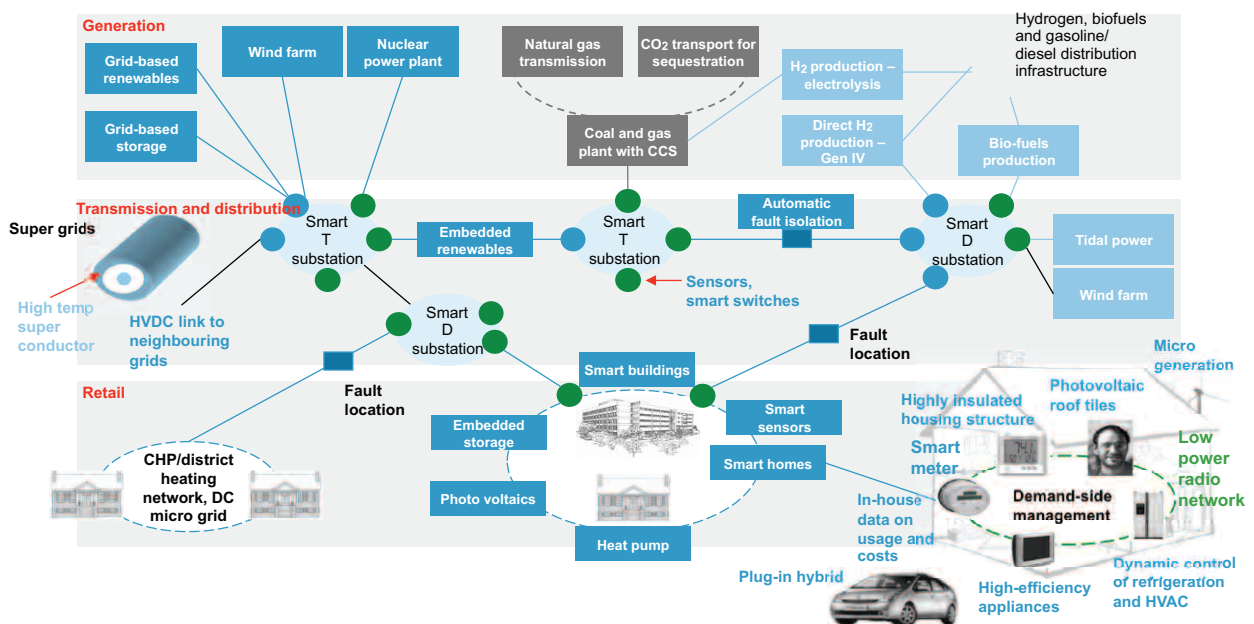
A smart grid uses sensing, embedded processing and digital communications to enable the electricity grid to be:

- *observable* (able to be measured and visualized)
- *controllable* (able to be manipulated and optimized)
- *automated* (able to adapt and self-heal)
- fully *integrated* (fully interoperable with existing systems and with the capacity to incorporate a diverse set of energy sources).

A smart grid will create the platform for a wide range of advanced and low-carbon technologies.

The smart grid, as defined in Figure 2, encapsulates embedded intelligence and communications integrated at any stage from power generation to end point consumption. To date, the majority of the industry debate has centred on smart meters and advanced metering infrastructure – devices designed to accurately measure and communicate consumption data in the home or office environment. Confusion can arise if the term “smart meter” is used synonymously with “smart grid”. One of the objectives of this paper is to provide some clarity regarding this misunderstanding. The reality is that, with the holistic smart grid, the smart meter becomes just one more node on the network, measuring and relaying flow and quality data.

Figure 2: Smart grids – A holistic definition



Today's Importance of Smart Grid

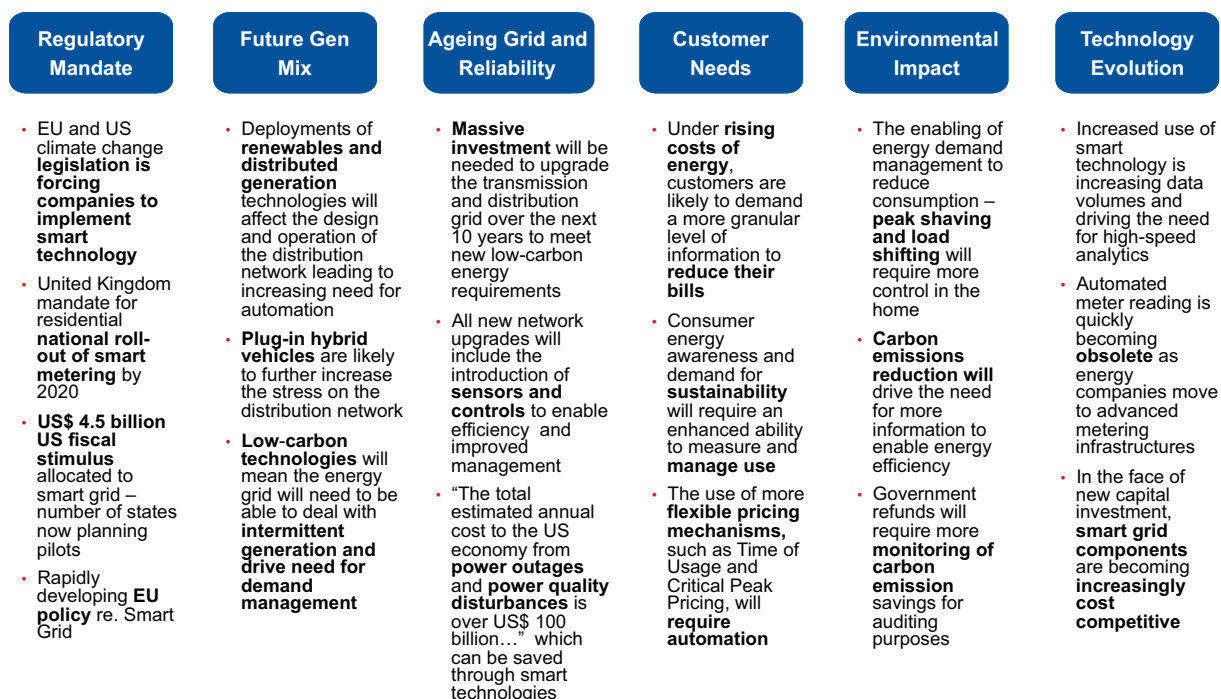
A confluence of factors is driving the need for investment. Smart grids have the ability to fundamentally change the way people interact with their electricity supply.

A number of factors are converging, driving the energy industry towards a smart grid (as outlined in Figure 3). These factors are bringing the agenda to the attention of politicians and regulators and driving a need for industry solutions. The requirement to act now is compounded by the non-insignificant lead time on these technologies. The opportunity cost of not investing at this stage firstly could create a rate-limiting step in the renewables and electric vehicle ramp-up, and secondly could result in mass investment in “dumb” infrastructure which later has to be upgraded at greater total cost to the customer.

A smart grid will exhibit seven key characteristics:

- **Self-healing and resilient:** A smart grid will perform real time self-assessments to detect, analyse and respond to subnormal grid conditions. Through integrated automation, it will self-heal, restoring grid components or entire sections of the network if they become damaged. It will remain resilient, minimizing the consequences and speeding up the time to service restoration. The modernized grid will increase the reliability, efficiency and security of the power grid and avoid the inconvenience and expense of interruptions – a growing problem in the context of ageing infrastructure. In the US alone, interruptions in the electricity supply cost consumers an estimated US\$ 150 billion a year.⁸ It will reduce vulnerability to the growing threats of natural disasters (hurricanes, ice storms) as well as cyber-attacks and terrorism.
- **Integration of advanced and low-carbon technologies:** A smart grid will exhibit “plug and play” scalable and interoperable capabilities. A smart grid will permit a higher transmission and distribution system

Figure 3: Factors driving smart grid



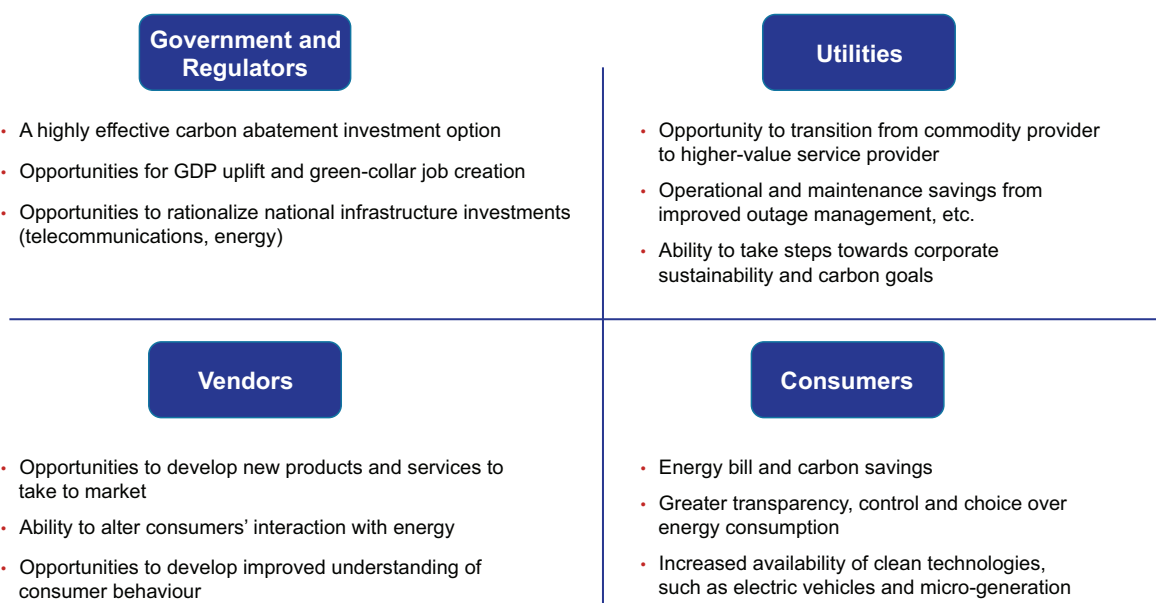
penetration of renewable generation (e.g. wind and photovoltaic solar energy resources), distributed generation and energy storage (e.g. micro-generation). Case studies from Belgium demonstrate that as low as a 7% penetration of distributed wind turbines on the low voltage network can begin to cause major problems on the distribution network.⁹ To mitigate the intermittent nature of renewable generation, the smarter grid can leverage embedded storage to smooth output levels. Without a smart grid, diurnal variations in generation output will typically require renewables to be backed with fast ramp-up fossil fuel based plants. Smart grids will also provide the necessary infrastructure for mass adoption of plug-in hybrid and electric vehicles, ultimately enabling both scheduled dispatch of recharge cycles and “vehicle-to-grid” capability. Such networks will allow society to optimize the use of low-carbon energy sources, support the efforts to reduce the carbon intensity of the transport sector and minimize the collective environmental footprint.

- **Enable demand response:** By extending the smart grid within the home (via a home area network), consumer appliances and devices can be controlled remotely, allowing for demand response. In the event of a peak in demand, a central system operator would potentially be able to control both the amount of power generation feeding into the system and the amount of

demand drawing from the system. Rather than building an expensive and inefficient “peaking plant” to feed the spikes in demand, the system operator would be able to issue and demand response orders that would trigger a temporary interruption or cycling of non-critical consumption (air conditioners, pool pumps, refrigerators, etc.).

- **Asset optimization and operational efficiency:** A smart grid will enable better asset utilization from generation all the way to the consumer end points. It will enable condition- and performance-based maintenance. A smart grid will operate closer to its operational limits, freeing up additional capacity from the existing infrastructure; this remains an attractive proposition when a US study demonstrated that transmission congestion costs Eastern US consumers US\$ 16.5 billion per year in higher electricity prices alone.¹⁰ Smart grids will also drive efficiencies through reductions in technical and non-technical line losses – estimates are that 30% of distribution losses could be mitigated.¹¹
- **Customer inclusion:** A smart grid will involve consumers, engaging them as active participants in the electricity market. It will help empower utilities to match evolving consumer expectation and deliver greater visibility and choice in energy purchasing. It will generate demand for cost-saving and energy-saving

Figure 4: Opportunities and benefits of a smart grid



products. In a world where consumer expectations and requirements are growing, smart grids will help educate the average consumer, foster innovation in new energy management services and reduce the costs and environmental impact of the delivery of electricity.

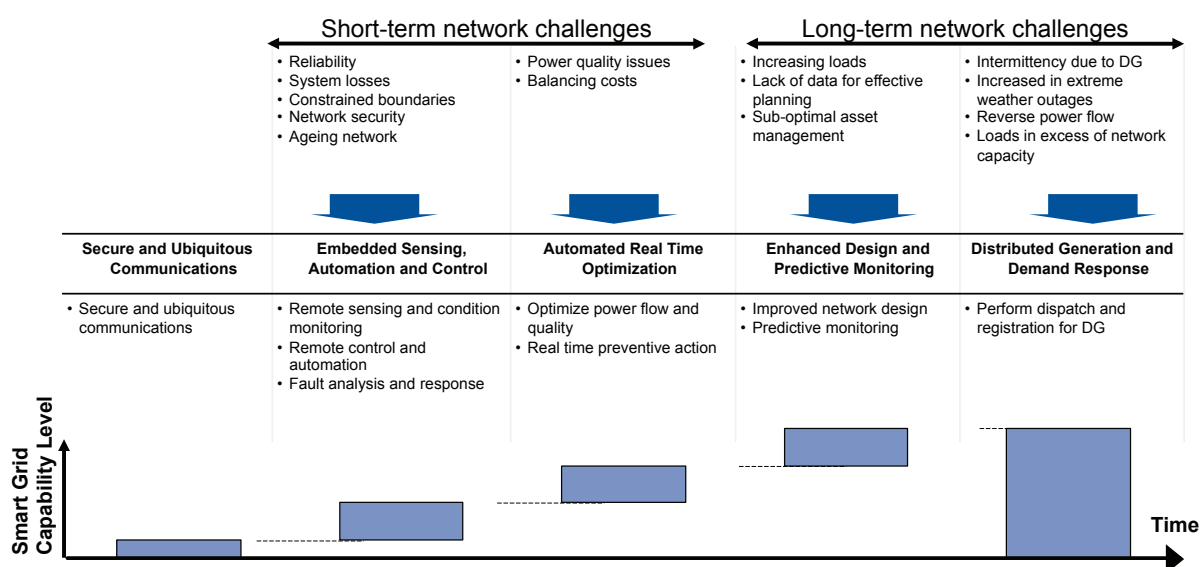
- **Power quality:** A smart grid will have heightened power quality and reductions in the occurrence of distortions of power supply. As the load demands increase on an exponential path, power quality degradation will manifest as more of an issue, in turn requiring distributed monitoring and proactive mediation. This will confluence with a decrease in tolerance for power quality variances from modern industry, particularly the hi-tech sector and the higher costs of such quality issues as economies grow.
- **Market empowerment:** A smart grid will provide greater transparency and availability of energy market information. It will enable more efficient, automated management of market parameters, such as changes of capacity, and enable a plethora of new products and services. New sources of supply and enhanced control of demand will expand markets and bring together buyers and sellers and remove inefficiencies. It will shift the utility from a commodity provider to a service provider.

1.4 What are the Technical Capabilities that Deliver a Smart Grid?

Layers of technical capability will be applied to a power grid to deliver these smart grid characteristics:

- **Secure and ubiquitous communications:** resilient, two-way digital communication infrastructure exhibiting appropriate bandwidth and latency and enabling communications from generation source to consumer end point
- **Embedded sensing, automation and control:** monitoring and sensors (voltage, current, etc.), automated switches and controls and micro-processing capability to enable the electricity network to respond to real time conditions
- **Automated real time optimization:** advanced monitoring, sensing and controls, decision support algorithms, low latency communications to support active load balancing and self-correct for interruptions and power quality issues in real time
- **Enhanced design and predictive monitoring:** asset data collection, analytics and advanced visualization techniques integrated in to the utility enterprise systems to provide the tools to optimize network planning and predict and respond to anticipated equipment failure

Figure 5: Smart grids – Incremental layers of capability



-
- **Distributed generation and demand response:** simplified interconnection standards, two-way power flow capabilities and more effective load balancing techniques to allow distributed generation and energy storage to be incorporated seamlessly into the transmission and distribution network; energy management systems will track the balance of supply and demand on the network and control consumer devices to optimize 24-hour energy consumption

1.5 One Size Does Not Fit All

Implementation of a smart grid will be step-wise and tailored to fit, rather than one-size-fits-all. The architecture will be a product of the legacy infrastructure and “to-be” vision for a smarter grid.

When developing an understanding of smart grids, it is important to recognize both the common technical principals (embedded intelligence and ubiquitous communications) and the geographic variances which exist, and to move away from a one-size-fits-all definition.

Each smart grid implementation will have an architecture that will be a function of:

- **Legacy characteristics of the power grid:** the condition of the existing smart grid infrastructure will be an important determinant of the smart grid strategy. The degree of urgency for implementation will vary, depending on the relative state of repair and the remaining capacity. The current and future generation mix will also determine both the need and scope for the smart grid. In some instances, a smart grid could be a complete new build infrastructure, for example, to support greenfield sustainable cities, which will offer several more degrees of freedom for the strategy and implementation.
- **Primary drivers for implementation:** the specific tactical and strategic objectives which the smart grid is designed to achieve will also vary in each instance, reflective of the region’s challenges and ambitions. The focus could be on either transmission or the distribution network, where separate suites of technologies might be required. The primary drivers could range from enabling a city environment to integrate low-carbon technologies to reducing the risk of outages from extreme weather events. These implementation drivers will define the “to-be” vision of capability for the smart grid implementation.





With both the legacy and the vision, the delta which the smart grid implementation is intended to close can be defined. Relating to the nature of this delta, the smart grid will be configured differently to prioritize the capabilities required to deliver specific business outcomes.

It is important to recognize that a smart grid implementation is unlikely to be a big bang. The complexity and scale will require an incremental approach with the marginal capabilities, packages of hardware, software and communication solution, phased over time. Staged releases of logical capabilities which gradually transform the grid’s functionality would be expected.

One of the first decisions with the smart grid strategy will be which communications technology to adopt. Utilities will have to be forward-minded to ensure that the backbone they deploy has sufficient bandwidth and latency to support the end game functionality of the smart grid. Utilities should also be cognisant of the option for installing smart grid component technologies/solutions that can be “lit up” at a later stage as the communications infrastructure is rolled out and/or the enterprise systems are successfully integrated.

Below, some representative smart grid archetypes are identified, and the drivers and capabilities likely to be prioritized in initial releases are examined. None of the examples listed has a fully fledged smart grid today, but many have identified the need for change and have begun developing strategies for change. The archetypes are not intended to be exhaustive, but rather provide some examples and templates for what smart grids will look like in different regions. The archetypes help crystallize the differences in drivers; it is recognized that, within one geography, multiple priorities will be at play and, in this instance, multiple archetypes will apply. In each case, the legacy and hierarchy of outcomes will define the parameters of the journey towards a smart grid, and the transition will see multiple releases over time that will build layers of incremental capability that will ultimately deliver the desired outcomes. This staggered release strategy will allow the utility to manage the transition at a pace that does not compromise grid performance.

Seven key smart grid archetypes provide logical groupings for implementation architectures. They are intended to crystallize the differences in drivers; it is recognized that, within one geography, multiple priorities will be at play and, in this instance, multiple archetypes will apply.

Archetype	Description
<p>1. Aging Infrastructure E.g. New York</p> <p>Key drivers</p> <ul style="list-style-type: none"> • Preventing energy loss • Reducing costs • Increasing reliability and resilience to threats <p>Capabilities</p> <ul style="list-style-type: none"> • Secure and ubiquitous communications • Remote sensing and condition monitoring • Remote control and automation • Fault analysis and response • Optimize power flow and quality • Real time preventive action • Improved network design 	<p>Several major cities around the world are struggling with outdated energy grids that have outlived their useful life and failed to evolve with the demands of modern society. In the US, Canada and many parts of Europe, the grid is now 60+ years old and major infrastructure investment is overdue.</p> <p>Reducing costs and preventing energy loss are key drivers of the business case in these cities, as opportunities for maintenance cost reduction and efficiency gains are significant.</p> <p>Smart grid implementations in these cities are likely to focus on replacing distribution and transmission assets, as these are key drivers of costs. Furthermore, the ability to predict and avoid power failures through network intelligence will be important.</p> <ul style="list-style-type: none"> • A good example of this archetype is New York City. Reliability will be a key factor; the Northeast blackout of 2003 left 45 million people across eight US states without power, including all of New York City, resulting in huge economic losses and several fatalities. The US Electricity Advisory Committee estimates that a smart grid would enable a 90% reduction in the cost of disturbances to business. • New York sources a significant portion of its electricity from Canada, meaning vast transmission networks are an important source of costs. 
<p>2. Island Networks E.g. Singapore</p> <p>Key drivers</p> <ul style="list-style-type: none"> • Incorporating renewables • Enabling substitution technologies • Optimizing consumption <p>Capabilities</p> <ul style="list-style-type: none"> • Secure and ubiquitous communications • Remote sensing and condition monitoring • Remote control and automation • Predictive monitoring • Perform dispatch and registration for DG 	<p>Self-contained islands may be ideal environments for spearheading smart grid adoption, as small urban areas are conducive to electric vehicle use and relative simplicity of regulatory environments enables swift action. Furthermore, islands are often heavily dependent on external sources of energy and highly vulnerable to the effects of global warming, providing further incentive to diversify the energy mix towards micro-generation and renewables.</p> <p>The key focus in this type of smart grid will be on the distribution grid, through enabling substitution technologies and distributed generation. Import/export interconnections and sub-sea transmission interconnections will also play a role.</p> 

Archetype	Description
	<p>A good example is Singapore, recently pegged by an international panel of experts as an ideal place to launch an EV network.¹² Key characteristics:</p> <ul style="list-style-type: none"> • A contained urban area – (the longest east-west stretch is just over 40 km and north-south stretch about 20 km) • Top-down policy environment which will ensure rapid deployment of a complicated and ambitious system once there is buy-in from the top • Singapore has one of the most efficient and reliable electrical grids in the world and a sophisticated IT sector, a good platform for smart grid roll-out • Environmental concerns – key vulnerabilities to climate change include coastal land loss, increased flooding, impact on water resources and spread of disease • Energy security concerns – No indigenous oil and gas resources. Hydro, geothermal and wind power are not available in Singapore, while nuclear energy is not feasible due to population density and lack of scale. Plugging solar panels into the grid is a potential solution • Singapore believes the current liberalized market structure should provide a platform for innovation, while correcting market failures with market-based instruments or through imposing standards and regulations¹³ • An ambition to develop leading-edge expertise that can be exported to larger markets will also drive the smart grid effort and boost the business case. However, a lack of economies of scale is one challenge that will need to be overcome

3. Concentrated Intermittent Renewables E.g. US Midwest

Key drivers

- Incorporating renewables
- Preventing energy loss
- Optimizing consumption

Capabilities

- Secure and ubiquitous communications
- Remote sensing and condition monitoring
- Remote control and automation
- Predictive monitoring
- Improved network design
- Optimize power flow and quality
- Perform dispatch and registration for DG

Renewable energy sources, such as wind farms, are more location-dependent than conventional power sources, contingent on where the natural resources are most abundant (wind/tides/sun) and where there is sufficient space and availability of planning permission.



Typically, these factors lead to geographic separation between concentrated renewables and centres of demand, often cities. This increases the need for efficient long-distance transmission networks.

Alternative energy sources also have a high level of variability in electricity output, causing variability of the power supply. This leads to intermittency issues as electricity transmission systems require a real time balance in supply and demand to maintain network stability and security of supply.

Such issues can be met in several ways, some of which involve a smart grid, including using demand-side management and use of e-vehicles and vehicle-to-grid storage capacity, and some probably do not, such as greater use of flexible generation like gas turbines, or incorporation of storage. The benefit of a smart grid solution is that it helps avoid intermittent renewables being backed-up with fast ramp-up fossil fuel generation.

The United States Midwest exemplifies this archetype:

- “To accelerate the creation of a clean energy economy, we will double the capacity to generate alternative sources of energy like wind, solar and biofuels over the next three years,” said US President Obama in a February radio address. “We’ll begin to build a new electricity grid that will lay down more than 3,000 miles of transmission lines to convey this new energy from coast to coast.”¹⁴
- A key question is going to be how to get renewable power from the mountain states to the West coast, or to the centre of the country.¹⁵

Archetype

Description

4. Developing Economy E.g. Mumbai, Rio de Janeiro

Key drivers

- Increasing reliability and resilience to threats
- Incorporating renewables
- Reducing costs
- Preventing energy loss
- Optimizing consumption

Capabilities

- Secure and ubiquitous communications
- Remote sensing and condition monitoring
- Remote control and automation
- Fault analysis and response
- Optimize power flow and quality
- Real time preventive action
- Improved network design
- Predictive monitoring
- Perform dispatch and registration for DG

As economic growth continues in emerging economies, millions of consumers in countries such as China, Brazil and India are reaching levels of prosperity that will require substantially higher energy use. In many of these developing economies, energy theft is a growing problem and one of the biggest challenges that utilities are trying to address.



India's Ministry of Power estimates that about half of the electricity in the country is billed. The financial impact of technical and commercial losses has been estimated at 1.5% of GDP.

Brazil is another country with similar problems; the federal statistics institute, Instituto Brasileiro de Geografia e Pesquisa (IBGE), says that, by 2020, the number of residents living in slums could climb to 55 million, equivalent to 25% of the national population. Access to basic services like electricity in Brazil's low-income communities is limited, and slum residents in the country's south-east and north-east regions often resort to illegal power connections to meet basic needs such as refrigeration and lighting.¹⁶

Accommodating this demand growth and at the same time reducing non-technical losses will require significant new build of generation, transmission and distribution capacity. The case for smart will revolve around the grid's ability to reduce non-technical losses, integrate renewables and improve resilience to external threats.

Rio de Janeiro provides a good demonstration of the challenges and potential solutions and has a small pilot project underway:

- One local energy-distribution company, Ampla, was losing revenue from more than 53% of all the energy it supplied. Through implementing smart grid technology, it has been able to reduce losses to 1.6% of energy supplied¹⁷
- The key components included remote monitoring technology, feeding data to an operations centre every 15 minutes. Software systems then analyse the data and generate web reports, pinpointing transformers with higher than acceptable losses
- Furthermore, the ability to remotely disconnect culprits has been especially important, as it saves the cost of having to send someone to do it manually and overcomes the previous inability of connecting/reconnecting clients in violent areas controlled by drug dealers

Archetype	Description
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5. Hi-tech Manufacturing E.g. Silicon Valley	
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Key drivers

- Improving power quality
- Preventing energy loss

In many of the existing hi-tech manufacturing clusters, a high degree of power quality and reliability is critical to complete the day-to-day activities. The equipment used is typically extremely sensitive to power fluctuations, and any voltage surge, sag and momentary outage on the supply cause several tools, equipment and even entire production lines to malfunction, resulting in significant business losses.



The application smart grids features in the network, such as sensing, automated self healing and controlling mechanisms distributed throughout the network, can monitor power quality and in the majority of the cases trigger automatic responses ensuring a higher quality power in the network and less downtime.

Silicon Valley is a good example of this model:

- Silicon Valley is the leading hi-tech economic centre in the United States. The economy is highly dependent on the quality of the power supplied to many of the electronics manufacturers and IT houses spread around the region.

6. Distributed Generation and Storage E.g. Flanders, Belgium	
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Key drivers

- Incorporating renewables
- Enabling substitution technologies
- Optimizing consumption

Capabilities

- Secure and ubiquitous communications
- Remote sensing and condition monitoring
- Remote control and automation
- Real time preventive action
- Improved network design
- Predictive monitoring
- Perform dispatch and registration for DG

In most parts of the world, environmental awareness, the rising cost of energy and the lowering cost of technology such as solar panels are driving governments and citizens alike to increase the number and diversity of micro-renewable energy sources. Financial incentives by governments can cause relatively rapid increases in the penetration of these technologies (there are examples of feed-in tariffs which offer 10-fold the value of the energy). On-site photovoltaic panels and small-scale wind turbines are present-day examples; emerging resources include geothermal, micro-combined heat and power boilers, biomass, hydrogen fuel cells, plug-in hybrid electric vehicles and batteries.



Today's distribution system is designed to deliver energy in a single direction from the substation to the home. The integration of micro-generation goes against this design assumption and can risk exposing system and customer equipment to potential damage, decrease in power quality, decrease in reliability and extended time to restoration after outage.¹⁸

Such considerations are important in countries such as Belgium:

- A Belgian utility is working to adapt fast to the increase in micro-generation.

Archetype	Description
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- Feed-in tariffs of 45 cents for electricity placed back on to the grid have meant that individuals investing in renewables can break even just two years.¹⁹ Combined with fast turn-around planning permission, an average of 7% of kWh is now produced from decentralized power sources.²⁰ As a result, the utility is required to explore the use of smart technologies to support this new energy infrastructure.

7. Enhanced Resilience
E.g. New Orleans, North-east China

Key drivers

- Increasing reliability and resilience to threats
- Preventing energy loss
- Improving power quality

Capabilities

- Secure and ubiquitous communications
- Remote sensing and condition monitoring
- Remote control and automation
- Fault analysis and response
- Optimize power flow and quality
- Real time preventive action
- Predictive monitoring

A safer and more resilient network grid is essential to ensure progress and economic growth. Existing energy grids are vulnerable to external threats or attacks, such as natural disaster or cyber-attacks, putting at risk energy supply and availability.

“Implementing a next-generation electrical power grid is vital to strengthening ... resilience and promoting energy efficiency, security and alternative sources of power. Our nation is at a crossroads as our energy dependence and vulnerable critical infrastructures become significant liabilities to our security and resilience. Our current grid is highly vulnerable to severe disruption in the case of a catastrophic event.”²¹

The implementation of smart grids, using advanced communications and other electrical capabilities, can create a more dynamic and agile grid that enhances the resilience of the grid and ensures availability of energy supply.

Some regions have higher propensity to these situations, such as natural disasters, cyber-attacks or both, making them ideal for smart grid adoption.

Prime examples are New Orleans, with its high propensity for natural disasters, any major city vulnerable to cyber-threats and attacks, and the Harbin province within China, which has a susceptibility to outages due to ice storms.

Smart grid adoption would be able to avoid and prevent many of the problems resulted from these threats. Embedding smart technologies in smart grid functionalities such as early warning systems, self healing mechanisms and active temperature control can be on the front line to prevent outages and ensure energy supply.



2. Barriers to Implementation

Seven barriers are holding back the implementation of smart grids; none of which are insurmountable, as described in the next section. The paramount issue is a regulatory framework that is out of sync with today's industry needs and society's broader environmental objectives.

In the following section, the current challenges that are holding back investments in smart grids will be examined, before looking, in Section 3, at potential actions that could be taken to address them and accelerate the adoption of smart grid technologies. There are a number of factors that, in combination, are acting as a brake on smart grid investment, most of which are institutional and relate to the regulatory and policy frameworks that have evolved to support the existing power delivery system. Seven areas have been identified that will need to be addressed before smart grids become more widely adopted:

- 1. Policy and regulation** – In many cases, utilities do not get as far as a business case for the smart grid as there are regulatory and policy barriers in place that either create reverse incentives or fail to create sufficient positive incentives for private sector investment.
- 2. Business case** – Where policy-makers and utility executives are aware of the role that smart grids can play, they are often unable to make the business case for smart grid investments. Within the business case, two factors operate: first, the capital and operating costs are too high, as suppliers have not been able to achieve scale economies in production and delivery risk is priced in; and second, only those benefits that are economically tangible are factored in, while other ancillary and non-financial benefits are not included (e.g. the carbon benefits) or are aligned to the appropriate value-chain players.
- 3. Technology maturity and delivery risk** – A smart grid brings together a number of technologies (communications, power electronics, software, etc.) at different stages of the technology maturity lifecycle. In some cases, these technologies have significant technology risks associated with them because de facto or agreed standards have not emerged. In addition, there are only a handful of examples of large-scale implementation of more than 50,000 premises and therefore there continues to be significant delivery risk priced in to the estimates.
- 4. Lack of awareness** – Consumers and policy-makers are becoming increasingly aware of the challenges posed by climate change and the role of greenhouse gas emissions in creating the problem. In some cases, they are aware of the role of renewable generation and energy efficiency in combating climate change. It is much less common that they are also aware of the way that power is delivered to the home and the role of smart grids in enabling a low-carbon future.
- 5. Access to affordable capital** – Utility companies are generally adept at tapping the capital markets; however, where delivery risks are high and economic frameworks are variable, the relative cost of capital may be higher than normal, which acts as a deterrent to investment. Stable frameworks and optimum allocation of risk between the customer, the utility and government will be the key to accessing the cheapest capital possible. In the case of municipalities and cooperatives, this challenge may become amplified as the ability to manage delivery risk is reduced.
- 6. Skills and knowledge** – In the longer term, a shortfall is expected in critical skills that will be required to architect and build smart grids. As experienced power system engineers approach retirement, companies will need to transition the pool of engineering skills to include power electronics, communications and data management and mining. System operators will need to manage networks at different levels of transition and learn to operate using advanced visualization and decision support.
- 7. Cybersecurity and data privacy** – Digital communication networks and more granular and frequent information on consumption patterns raise concerns in some quarters of cyber-insecurity and potential for misuse of private data. These issues are not unique to smart grids but are cause for concern on what is a critical network infrastructure.

Of the seven barriers outlined above, the first three pose the most significant hurdles, but, if addressed, will go a long way towards creating an environment that will encourage investment in smart grids. None of these barriers is insurmountable; however, it is important to understand the root cause of the issues before developing strategies to break them down. In the following sections, each area will be looked at in more detail with examples that highlight the challenge.

2.1 Policy and Regulation

Policy and regulatory frameworks need to adapt; today's frameworks evolved to encourage competition in generation and supply of power rather than to promote clean energy supply.

The current policy and regulatory frameworks were mostly designed to deal with standard networks and utility operating models; in effect, “an all-you-can-eat buffet of electrons”. In some cases, this has evolved to encourage competition in generation and supply of power. With the move towards smart grids, the existing policy and regulatory frameworks will need to evolve to encourage the right behaviours and incentives for investment. The new frameworks will need to align the interests of consumers with utilities and suppliers to ensure that the societal goals are achieved at the lowest cost to the consumer (either through the utility or tax bill).

In most cases, governments set policy while regulators monitor the implementation, protect the consumer and seek to avoid market abuse. Over the last two decades, the trend towards liberalized markets in many parts of the world has focused the attention of policy-makers on enabling competition and consumer choice. In economic terms, the onus has been on the private sector to make capital investments and to earn regulated rates of return on those assets. In a mature market model, this is a relatively low risk, low reward endeavour. The regulatory models have evolved to become more and more effective at avoiding market abuse and regulating rates of return.

Moving forward, the regulatory model will have to adapt to balance a suite of outcomes in which carbon reduction and security of supply take a more prominent place in the defined outcomes. As a consequence, trade-offs may need to be made with the degree of market competition and cost to the consumer. If policy-makers and regulators see long-term carbon reduction and security of supply as important outcomes, they will need to rebalance the regulatory incentives to encourage privately financed utilities to invest at rates of return that are commensurate to the risk. The relative risk profile for smart grid investments, given the technology and delivery risks outlined above, will require policy and regulatory frameworks that allocate risk to the parties that can diversify it most effectively. This may mean creating frameworks that allow risk to be shared between customers (either through their utility bills or taxes), and shareholders, so that risks and rewards are balanced at least aggregate cost to the customer.

As it stands, there are few examples of where this is being done effectively. Section 3 will look at some of the mechanisms that are being used or suggested in countries that are wrestling with this challenge.

2.2 Business Case

By purely quantifying the utility's financial benefits which could be realized today, the smart grid business case fails to recognize the broader societal value proposition.

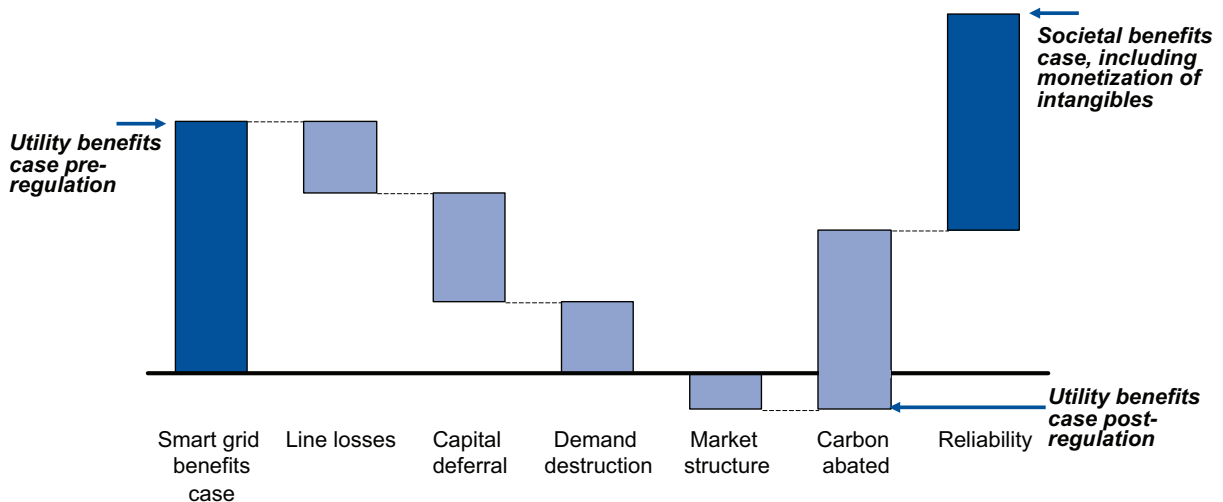
In those cases where more forward thinking regulators and policy-makers have commissioned business cases, or progressive utilities have taken it upon themselves to push the issue, there has been a mixed set of results. The majority of examples results in negative business cases, undermined by two fundamental challenges:

- **High capital and operating costs** – Capital and operating costs include large, fixed costs attributable to the ubiquitous communications network. Hardware costs do not factor in significant improvements in economies of scale and production innovation, and software integration assumes significant delivery and integration risks.
- **Benefits are constrained by the regulatory framework** – When assessing the benefits, business case modellers tend to be conservative in what they can realize as cash benefits to the shareholder. For example, in many cases, line losses are considered as a pass-through to the customer and, therefore, any reduction in losses would have no net impact on the utility shareholder.

There is a clear link between the business case and many of the barriers that have been identified in this section. Regulatory and policy frameworks determine the economics of the business and therefore drive what can be accounted for in the benefits case. The regulatory frameworks and accounting rules will determine what benefits can be monetized and which remain neutral to the utility.

As illustrated in Figure 6 (see next page), the smart grid benefits case may begin as positive but, as misaligned policy and regulatory incentives are factored in, the investment becomes less attractive. A broader societal benefits case which monetizes externalities is required.

Figure 6 – Illustrative graph of smart grid benefits case



The first consideration is the incentive to remove inefficiencies from the system. Utilities may be fully compensated for the line losses on their network; therefore, this common good fails to be monetized by the utility chief financial officer. Utilities also often recoup a return on their assets deployed; therefore, capital deferral (especially within generation) again is discouraged. The electricity demand destruction realized through empowered consumers will strip profits from the retail business, and finally the utility market structure may create a situation whereby those that are required to invest realize limited benefit. The end result is that, once the reverse incentives have been factored in, the utility's purely financial smart grid business case provides a mildly negative view. But this perspective fails to realize the value of externalities; it discounts the positive effects of reduction in greenhouse gases and improved network reliability. Section 3 will look at how the parameters of the business case can be broadened through changes to the regulatory accounting guidelines and innovative incentive structures.

On the cost side of the equation, there is no avoiding the fact that smart technologies are expensive to implement, and at the current level of maturity it is right to factor in the risk associated with delivery. However, there are ways in which policy-makers and regulators can help mitigate that risk and lower the fixed cost of communications by seeking economies of scale and scope with broader digital communications strategies (high speed wireless and/or fibre roll-out). Going forward, it can be expected that there is a move away from utility-specific business cases to broader societal value propositions that look

across the entire value chain and seek to identify winners and losers. In this way, a framework is created to reallocate value accordingly to aligned incentives.

2.3 Technology Maturity and Delivery Risk

Smart technologies vary in technological maturity, with the challenges of data management and secure, ubiquitous communications proving to be key considerations.

Within the smart grid technology landscape, a broad range of hardware, software and communications technologies, at various levels of maturity, can be seen. In some cases, the technology is well established; however, in many areas the technologies are still at a very early stage of maturity and have yet to be trialled at significant scale. At a component level, this means that many of the core elements of the solution are not being produced at a significant enough scale to make them economically viable. With so few large-scale pilots under way, the industry is still at the earliest stages of understanding how to manage the explosion of data that comes from the embedded sensing on the network. As the technologies mature and standards (imposed or de facto) form, the delivery risk will decrease but, until that is the case, the risks will be factored into the business cases, making it harder to justify.

On the hardware side, rapid evolution of designs and functionality is seen from vendors all over the world. Over the last three years, this space was being led by new companies that were innovating rapidly and developing integrated product sets that operated within their own ecosystems, using proprietary data protocols and sometimes even their own communications solution. More recently, these companies have evolved to become more agnostic to the communications solutions and more focused on operating within a suite of hardware and software solutions. In addition to this trend, there is increasing interest from the more established hardware providers as policy-makers, regulators and utilities begin to make more significant commitments to smart grids. This trend is expected to continue with increasing competition from Asian manufacturers and, as a consequence, standards will naturally form and equipment costs will drop as economies of scale arise and competition increases.

On the software and data management side, the critical challenges to overcome relate to the integration of multiple products sets and the management of data proliferation. With multiple software providers come multiple data formats and the need for complex data models. In addition, the proliferation of data puts stresses on the data management architecture that are more akin to the telecommunications industry than the utilities industry. Many of these issues are currently being addressed in pilots such as SmartGridCity™ and, as a consequence, the delivery risk will reduce as standard architectures become established best practice. (SmartGridCity™ is a trademark of Xcel Energy.)

At present, communications are presenting a real challenge as utilities struggle to find a common architecture that provides the right balance of latency and bandwidth to satisfy their requirements. There are many options that exist, from mesh radio solutions through 2G and 3G to power line carrier (PLC) and broadband over power line (BPL) and optical fibre. Each option has different performance characteristics depending on where and how it is implemented. Given the relatively high fixed cost of a ubiquitous communications platform, it is essential that it is designed with future functionality in mind and with an ability to scale to fit over time as additional demands materialize. In many cases, there is a confluence of government digital broadband communications infrastructure roll-out and smart grid communications infrastructure roll-out.

2.4 Increasing Awareness

The profile of smart grids among industry and the public needs to grow.

Consumers' level of understanding and engagement in how power is delivered to their premises is often low. Within the policy-making and regulatory arena, smart grids have only recently begun to attract interest where renewable generation has dominated the share of mind for low-carbon strategies in the past. This is compounded by the relatively short tenure (3-4 years) of an average PUC member. Within the utility industry itself, only recently have smart grids reached the boardroom and, even then, there remains a lack of consensus over what it is and how it is best applied. If smart grids are to gain traction, it will need to be clear to all the stakeholder groups what smart grids are, how they are different to the status quo and why they will be a central enabler of a low-carbon future:

- Consumers will need to be educated on how their energy consumption patterns at home, at work and in transit drive cost and have value
- Policy-makers and regulators will need to work across government departments, to understand how smart grid technologies will transform the networks and allow for the integration of future low-carbon technologies
- Utility executives will need to take a more holistic view of smart grid technologies, looking beyond the smart meter to a broader set of smart grid capabilities that will fundamentally change the operating model of the business; barely a process or system will remain untouched

2.5 Access to Affordable Capital

Utilities are a relatively risk-adverse, heavily regulated industry; they will need to adapt towards investing in less mature product sets.

In an environment of stable, predictable economic regulation, access to capital is well understood by all parties in the transaction. As the traditional capital investment and replacement programmes are supplemented with smart grid investment programmes, the pricing of the additional risk will mean that the utility weighted average cost of capital (WACC) will increase. Unless this is reflected in higher allowed rates of return for smart investments, the utility is unlikely to sanction the expenditure; furthermore, the increased cost of capital will

further degrade the business case. In the long run, it is expected that the risk profile return to something closer to the current state as new, stable economic frameworks come into play, delivery and technology risks unwind, and risk is equally and optimally shared across the value chain.

If long-run, marginal costs of hardware are to drop, the current low-volume vendors will need to scale up production by investing in manufacturing innovation and mass production facilities. To access the capital required for this transition at a reasonable cost, they will need to demonstrate that their risk of technology obsolescence is low and that their volume projections are stable and predictable. As it stands, there are many technologies vying for similar functionality and little in the way of firm commitments to volume purchases.

2.6 Skills and Knowledge

Smart technologies will require specialist skills to develop, implement and maintain the new energy system. New skills and knowledge need to be injected into an ageing industry workforce.

At this stage in the development of smart grids, there are such a limited number of large-scale pilots that getting access to leading industry architects is relatively easy. As the number of projects proliferates, the demands will grow for best practice documentation and information transfer from the original set of communications, data and system integration architects to the new projects. The existing population of utility engineers has developed deep skills in analogue electrical engineering; however, as the utilities drive towards smart grids, there will be a demand for a new skill set that bridges the analogue/digital divide and brings new skills in communications, data management, decision support and analytics.

Over the last two decades, the ageing workforce trend has largely gone unchecked and, as such, many utilities in the developed economies are destined to lose a generation of power system engineers at a time when they will be needed most to transition the existing networks to become smart grids. To address this challenge, a new cadre of engineers will need to be trained to manage the transition and to build an expanded set of skills that will help them design and build physical, communications and data architectures that will support the new grid. This transition will take investment of time and resources from government and the private sector to support education programmes that will create the engineers of tomorrow.



In the future, there will be a need for a broader knowledge base that can be tapped by entities choosing to transition towards smart grids. Much of the progress to date has been made by private companies developing and patenting new technologies, processes and architectures. Despite the current drive by the US administration to foster innovation in clean technologies in the US and the initiatives by FERC and DoE to drive standards, there is a risk that these technologies will become universally available but not royalty free. Those companies that are investing in intellectual capital will want reasonable returns on their investment. This issue will be addressed in the US through the NIST (National Institute of Standards and Technology) and may pave the way for a broader, global consensus on smart grid IP.²²

Further to the challenge of developing enough skills and knowledge to design and build the smart grid, a new workforce of system operators, asset managers and field crews will need to be trained to operate, manage, install and maintain the network. This exercise will require developing new competencies and skills in areas such as advanced decision support, visualization and communications engineering. The scale of this change in skills and competencies will require utilities to think hard about how they manage the transition to avoid overburdening staff with change.

2.7 Cybersecurity and Data Integrity

With enhanced digitalization and the greater availability of data comes greater risk of data mismanagement or intentional cyber-attack; such risks should be effectively assessed and managed.

With the transition from an analogue to a digital electricity infrastructure comes the added complexity of having to manage the security of the communications infrastructure and data collected. Concerns are now being raised about the integrity and security of what will become a critical national infrastructure. Articles have been released that suggest that a digital network is more susceptible to malicious attacks from software hacks.²³

In addition to these concerns over the vulnerability of the communications and control system, there are broader concerns over invasion of privacy and security of personal consumption data. The data and information collected on customer consumption (and potentially generation) could provide significant insight into customer behaviour and preferences. This information, while potentially valuable to the customer, service providers and system operators/planners, could be abused if the correct protocols and security measures are not adhered to.

In both of these cases, there are measures that can be put in place to mitigate these concerns. However, if not dealt with early in the process and in a transparent manner, the issue could shift public perception negatively and prove to be a barrier to adoption.

3. Solutions to the Barriers to Implementation

Despite the challenges laid out in Section 2, there are a number of concrete actions that can be taken to accelerate the adoption of smart grid technologies. At the root of the solution is a suite of systemic changes that need to be made to the way that policy-makers and regulators structure the economic incentives and align risk and reward across the value chain. By creating the right economic environment for private sector investment and thinking more broadly about the way that societal value cases are created and presented, the two most critical impediments will have to be overcome. Although national and transnational changes are required, there is a central role for cities to play in this process. Progressive and visionary cities will act as catalysts. By testing these solutions in increasingly larger environments, the entire industry will learn what it takes to implement smart grids successfully, and cities at the vanguard of the smart grid revolution will reap the rewards of developing an industry that is set to boom over the coming decade.

3.1 Creating Political and Economic Frameworks that Align the Stakeholders

Policy and regulatory frameworks will need to adapt to enable the low-carbon economy – aligning incentives for smart grid investment for both integrated and non-integrated utility value chains.

As it stands, the regulatory and policy frameworks in place in most locations are not designed to encourage the transition towards a smart network infrastructure, and in some cases the frameworks create negative incentives for investment. In a few cases, ambitious attempts have been seen to redress the balance and encourage investment in smart grid technologies. The final design of the regulatory framework will differ from location to location and will need to reflect the legacy environment (level of market liberalization, age and history of assets, ownership structures, etc.), desired outcomes and proposed strategy for transition. In each case, economists and lawyers will need to assess the frameworks and bring to bear a suite of potential mechanisms that create the right incentives across the entire value chain, allocate risks optimally, protect private investors against stranded asset risk and deliver the outcomes at the lowest cost to the consumer (through their bills and/or taxes). This section will tackle a number of critical policy issues and propose potential remedies (some of which are already being trialled). It has been deliberately chosen to stay at the level of basic principles, given that the details will differ from instance to instance; however, a number of universal principles should generally be applicable:

- **Decoupling** – In most cases around the world, utility revenues are a function of the commodity price and volume of that commodity sold. In these cases, there is a negative incentive to reduce consumption. In some cases, regulators have introduced specific energy efficiency incentives; however, in the US, some regulators have gone further and decoupled utility rates from the volume of the commodity that they are selling. By guaranteeing a rate of return on the installed asset base independent of the consumption levels, the incentive to drive sales is reduced. Decoupling does not, however, address the issue of “gold plating”, as the utility is still remunerated on asset base installed. However, this is not a new issue and regulators have developed methods to address this. In some cases, regulators may also want to create stronger incentives for volume reduction in the domestic market or flattening of peak load. However, decoupling is only intended as a transitional measure to manage the transition from a commodity-based business model to a service-based business model. In the long-run, regulators, policy-makers and utilities will need to transition towards a model that rewards efficiency, low-carbon generation and flexibility for the consumer.
- **Output-based regulation** – As regulators and policy-makers consider the best frameworks for smart grid investment, it is worth considering a greater level of output regulation. If it is assumed that similar regulated return models will be used in the future, it is worth considering linking bonus/penalty mechanisms to the rate of return to encourage delivery of the outcomes defined in the smart grid vision (those outcomes specified during the design and architecting phase). In principle, the utilities that are able to deliver the most efficient network per unit of electricity generated should get the highest rate of return.
- **Managing telecoms investments** – Telecoms infrastructure will form a significant proportion of the total investment in smart grids and has potential overlap with other aspects of the broader economy. In many developing and developed economies, the growth of a high-speed data and voice infrastructure (both wired and wireless) is a fundamental aspect of their future economic growth plans. The roll-out of these networks will cover similar footprints and may present opportunities to drive economies of scale and scope. Customers should not have to bear the burden of multiple coincident communications networks unless it is strictly necessary for reasons of security. Furthermore, by piggy-backing the existing communications infrastructure where possible, it will improve the business case for marginal improvements in smart grid functionality. In many cases, telecommunications and energy regulators have separate remits. Going forward, these regulators will have to work more closely together to agree on

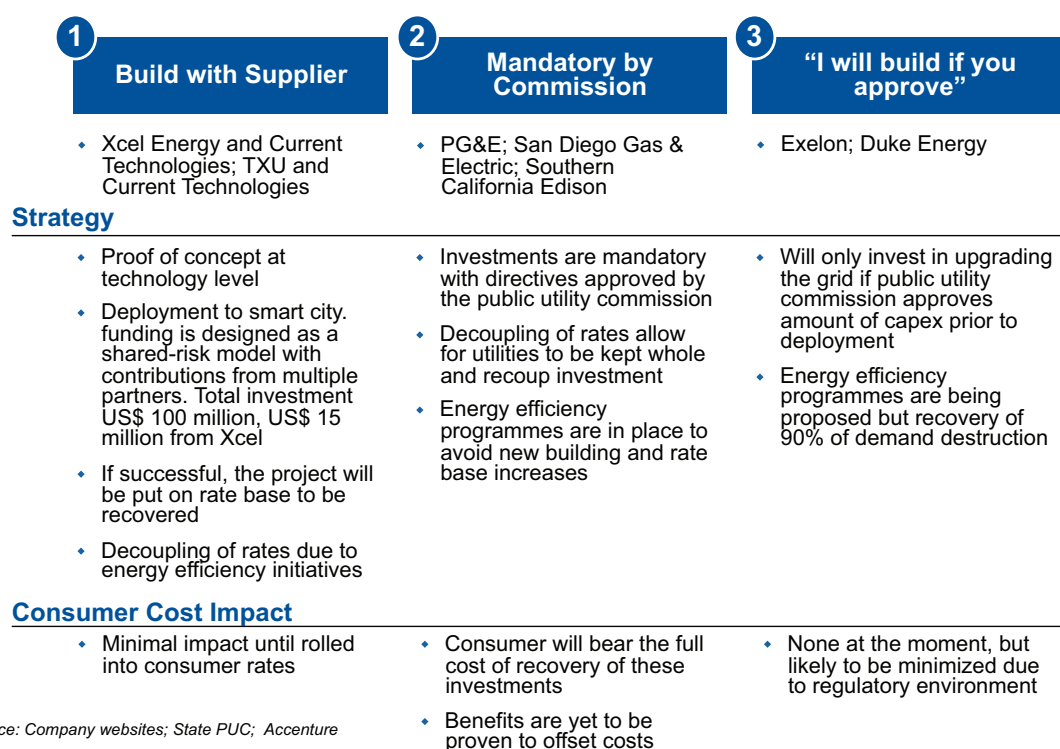
spectrum allocation, standards and cost/risk allocation. The same is true of policy-makers who will be responsible to consumers and taxpayers for delivering telecommunications and energy infrastructure at the lowest total cost of ownership.

- **Improved allocation of risk** – As mentioned in Section 2, the technological and delivery risk associated with smart grid implementation is significant, although it will decrease over time as more issues arise and are addressed. In the meantime, it is important that the regulatory frameworks are structured to allocate risk to the parties that are best able to manage it and diversify it. Every party in the value chain should shoulder some of the risk to align incentives, but some parties are more able than others to manage the risk. When designing the frameworks for delivery of the smart grid and awarding contracts, it should be clear that utility shareholders must hold some of the risk, but only sufficient risk to make them act in a way that aligns their interests to those of the consumer, and to a level that is material but not so severe that it is a disincentive to engaging in the project. By balancing bonus/penalty mechanisms at a material level, there will be improved alignment of incentives. In addition to creating the right incentives

for the utility, there should be careful consideration of how much of that risk the utilities can pass on to the suppliers and contractors. If the risks are simply passed through to the suppliers and contractors but the benefits are kept by the utility, the alignment breaks down. All parties should have positive and negative incentives in the framework for delivery.

- **Migrating value across the value chain in a deregulated market** – Although the process of deregulation has delivered significant cost savings for the consumer in many deregulated markets, it does tend to make the process of transition to a smart grid more complex as there are multiple private sector parties involved with varying potential to win and lose. In each deregulated market, it is important to look at the entire length of the value chain and understand where investments will need to be made and where benefits will accrue. It will then be down to the economists to work out how best to migrate the cost and benefit across the value chain to make sure there is an equal alignment of incentives and delivery of benefits to the consumer. As with the private sector, if consumers are being asked to shoulder significant elements of the risk, they should also see the greatest percentage of the reward.

Figure 7 – US regulatory model examples



Source: Company websites; State PUC; Accenture

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- **Dealing with stranded assets** – In some cases, there will be a significant legacy of installed assets that may become stranded by the transition to a smarter grid. In deregulated markets, this may mean that some players in the value chain will lose out significantly from this technology. While this could be considered to be a natural risk of doing business, there will be calls for mechanisms to smooth the transition. If some stakeholders are set to lose significant sums from the process of modernization, there will be strong incentives for them to delay the transition. Whether this is dealt with through the regulatory mechanism or allowed to play out without interference will be a political decision, but it could put significant stress on the transition. This issue has been faced a number of times already in other areas, and the same mechanism would apply but should be considered on a case by case basis.
 - **Funding of pilots** – If smart grids are to move forward at a rate that will help society deliver its ambitions to reduce greenhouse gas emissions, there will be a need for many, coordinated smart grid pilots, which then move quickly via effective dissemination of best practice to full-scale implementation. These pilots will need to vary in size and scope to ensure a broad spectrum of understanding of the risks and mitigations that need to be addressed to make smart grid value cases more attractive. At present, pilots such as that at SmartGridCity in Boulder have been reliant on the investment of private sector companies and have been conducted at significant risk. Since the announcement of the fiscal stimulus packages in the US and elsewhere, there has been a rapid increase in the level of interest in smart grids and potential trials. To get best value for money for the consumer and taxpayer, these pilots will need to coordinate scope and size. They will need to be funded or underwritten by either taxpayers or consumers with incentives placed on the parties engaged to share outputs and learnings so that consumers can mutually benefit from investments made elsewhere. Recently, a number of strategies have been adopted by utilities to encourage regulators and policy-makers to agree to pilots. A subset of US examples are outlined in Figure 7.

3.2 Moving Towards a Societal Value Proposition

A large proportion of the smart grid value proposition resides in its benefits to the public sector and to society as a whole. A more holistic perspective is required to capture and quantify externalities such as avoidance of power disturbances and carbon savings.

The business case for smart grids today is defined in a narrow context that prices risk in to the cost and underplays the potential benefit. The challenge will be to move from a utility-centric investment decision to a societal-level investment decision which recognizes the breadth of players and demonstrates the broader value of smart grids, which may or may not currently be rewarded within the confines of today's regulatory regime but remain valuable to both the consumer and society. Recognizing this value is the first step to appropriately rewarding it.

The business cases used for evaluating smart grids should be developed to encompass generation, transmission and distribution, retailers, customers and smart grid technology suppliers. Business cases should attempt to monetize appropriate externalities such as carbon. They should consider the gross impact at an economic level of building sustainable communications and energy infrastructure – GDP uplift, etc.

On the cost side of the equation, business cases should consider that both the price per unit and the assigned value for risk is expected to come down over the deployment lifetime of a smart grid programme. They should also consider whether costs can be shared through economies of scale and scope with other major infrastructure investments such as the national deployment of a broadband infrastructure. On the benefits case, they should recognize the potential of smart grids as an infrastructure provider to a low-carbon economy and attempt to monetize intangible benefits, such as carbon.

Achieving greater efficiency in energy delivery – Efficiency reduces the need to maintain expensive and potentially carbon-emitting generation assets and helps reduce overall energy consumption. Smart grid business cases should take account of building greater efficiency



into the energy network (reduction in losses on the network, peak load shifting) which today are ultimately picked up by the consumer. New regulatory frameworks which reward utilities for minimizing the technical losses on their network will drive different behaviours. Regulatory frameworks which are more innovative in how they provide regulated return on assets and how they incentivize demand destruction will lead the way to smart grid deployments. Some strong examples are already seen today where regulators' energy efficiency programmes compensate generators for 90% of the value of demand destruction.

Enabling distributed generation and storage combined with new business opportunities – Smart grids will change where, when and how energy is produced. Each home and business will be enabled to become a micro-generator. Onsite photovoltaic panels and small-scale wind turbines are present-day examples; emerging resources include geothermal, micro-combined heat and power boilers, biomass, hydrogen fuel cells, and plug-in hybrid electric vehicles and batteries. As the cost of traditional energy sources continues to rise and the cost of distributed generation technologies falls, the economic case for this transition will build. Assuming a 10% penetration of distributed generation, technologies' smart, interactive storage capacity for residential and small commercial applications has been estimated to add US\$ 10 billion per year by 2020 to the US economy.

Facilitating electrification of vehicles – The ability to electrify the transport sector also hinges upon a smarter grid. Today's network is designed to provide approximately 1 kWh/home. The advent of electric vehicles and their charging requirements is likely to increase this dramatically. Early estimates are that the current distribution grid is not dimensioned for more than a 15-20% penetration of electric vehicles. The recent

launches of e-vehicles by several major manufacturers – GE, Toyota, Nissan, etc. – represent the bottom of the S-curve on these technologies. If their uptake is to be supported, it is imperative to plan ahead to put the platform infrastructure in place.

Carbon abatement – An important element to the rationale of deploying smart grids is the ability to save carbon, both directly through more efficient transmission and distribution of electricity and more indirectly through the ability to change consumers' behaviour and as an enabler for a raft of low-carbon technologies. Worldwide, smart grid technologies can prevent about 2,000 MMT CO₂ of emissions, or about 4% of worldwide emissions in 2020,²⁴ according to a recent study by The Climate Group. This, together with other information and communication technologies (ICT) opportunities (in the key areas of travel/transport, buildings and industry systems), suggests a potential reduction of about 15% of total worldwide emissions in 2020. Moreover, considering even a relative conservative future price of carbon, for example US\$ 20, would make the financial business case for smart grids immediately positive.

Some visionary utilities, such as Duke Energy, are beginning to quantify and assign monetary values to their smart grid value proposition. Duke's smart grid business case includes the avoided costs from improved reliability, the carbon savings from lowered maintenance truck rolls and the carbon and operational savings associated with the reduced need for peaking plants. The study demonstrates that 40% of the total value case for smart grids is societal.²⁵

However, societal value propositions for smart grids do not necessarily need to be limited to purely monetary benefits. A number of externalities are likely to not be readily converted into dollar values and, yet, still reflect changes that are considered valuable to society more broadly. Rather than trying to convert these benefits to a monetary figure and having to make significant assumptions that could undermine their validity, regulators and policy-makers could take the benefits in their existing format and build them into the economic framework of incentives by creating rate of return multipliers (both positive and negative) to encourage the right behaviour from utilities.

3.3 The Role of Standards

Debate exists around the relative importance of standards; the key is getting the right type of standards at the appropriate level within the architecture.

At face value, the rapid migration towards a set of standards seems the logical and lowest risk solution to decreasing the implementation cost and risks for smart grids. However, there are inherent risks in setting de jure standards too early in the maturity cycle for a technology that will need to be borne in mind as the industry is driven headlong towards a set of standards. With most technologies, a progression of formalization is seen through coalescence around specifications and requirements; through the formation of de facto standards towards de jure national and ultimately international standards. With smart grid technologies it is possible to see a rapid acceleration of this process in some markets, especially in the US, where the American Recovery and Reinvestment act mandates the creation of national standards and the process is already under way to create them. A similar acceleration is seen in the European market and is expected also in Asia.

There are pros and cons to rapid adoption of de jure standards. On the positive side, there is likely to be a more rapid reduction in the hardware and integration costs for deployment of smart grids as suppliers and utilities gravitate towards agreed standards. However, on the negative side, there is a risk that the standards could act as a barrier to innovation and constrain the ultimate functionality of the system in an area where the technology is still relatively immature. One example of where the haste to develop standards ultimately hampered functional innovation is in the mobile telephony industry. In the drive to define the standards in the US, the industry created solutions that constrained the US networks' ability to deliver value-added services such as text and multimedia messaging. In Europe, the GSM standard allowed more flexibility to network operators and as a result there was a more rapid adoption of text messaging and the resultant revenue uplift.

Given the complexity of the power industry, the multiplicity of interfaces, the level of capital investment and the strategic importance of critical national infrastructure, the case for rapid adoption of standards is strong. However, in the absence of de facto standards, the stakeholders in the process will need to pre-empt the future functional requirements of utilities and create standards that are flexible enough to allow for innovation in the products and services that can be offered on the back of the standard infrastructure.

3.4 Increasing Awareness of Smart Grids

The dissemination of clear, consumer-relevant smart grid information to the public domain will be a key accelerator for education across the stakeholder groups.

There is an imminent need to increase the amount and the quality of available information regarding smart grids across the board, from senior policy-makers and the C-suite of the utilities to the electricity consumers. Each stakeholder group will have a different set of priorities and motivations for learning about smart grids, and the content and direction of the education will need to reflect that need and provide the appropriate details in given areas.

The first step is to establish a clear, universal definition on the common principles of a smart grid. Lack of a consensus clouds the industry today. Smart meters (with both one-way and two-way communications) are discussed synonymously with a smart grid which delivers quite a different set of capabilities. Beyond agreement on a definition, the topic also needs to be discussed more holistically as a true enabler to the low-carbon economy, rather than as an investment decision to be taken purely within the boardroom of individual utilities. The societal benefits case for such investments warrants discussion across the public/private sector boundary to develop workable industry solutions.

The role of consumer education is not to be underestimated. To maximize the benefits of smart technologies, significant behavioural change will be integral. The participatory nature of the new network and the advent of energy management tool and services will fundamentally shift the way people value and interact with their electricity supply. The creation of user-friendly and innovative products and services will play an important role in engaging the public and articulating the answer to the question, "What's in it for me?"

Policy-makers and regulators will require help in quickly getting up to speed on this relatively novel concept to ensure that they are setting in place economic regulatory and market constructs which address the true needs of the industry. They will also need to ensure that they are aligned across political parties to deliver consistent messaging to their citizens. Forums and open discussions with utilities and technology suppliers will be an important element of this process.

Relatively quickly, utilities also need to obtain a base understanding of the technology, business case and implementation challenges of smart grids. They need to leverage the learnings from the handful of smart grid pilots which are live today. Utility executives need to begin factoring smart technology into their asset management planning and anticipating the impacts on both their business models and operations.

3.5 Creating a New Pool of Skills and Knowledge

Addressing the skills shortages and providing the infrastructure to facilitate cross-industry knowledge exchange is fundamental to moving the technology forward.

The “greying workforce” and shortage of engineering talent are already concerns within the utility sector. Successful implementation of the smart grid will require a large number of highly skilled engineers, particularly those trained to work on transmission and distribution networks. As such, a dramatically increased commitment to on-the-job training and workforce development will be required across the industry. In parallel, there is a need for investment in the development-relevant undergraduate, postgraduate and vocational training to ensure the building of a sufficient pipeline of next generation, smart-grid-savvy electrical engineers. Mechanisms such as the Green Jobs Act and Workforce Investment Act in the US provide initial examples of formalizing this investment.

Smart grid investors should also look beyond their national borders and recognize the wealth of engineering talent that is available globally. Today, China is the largest producer of engineering graduates in the world, with some 600,000 passing out of its colleges and universities last year. India is not far behind, producing slightly more than 500,000 engineering graduates a year.²⁶ In comparison, the United States produces only 70,000 engineering graduates every year. All of Europe produces just 100,000.²⁷ The ability to sensitively leverage this abundance of talent will help alleviate short-term bottlenecks in supply.

The investment should not be limited to the T&D engineering workforce; research and development skills and knowledge will also be fundamental to accelerating this sector. Studies and papers released by the US National Energy Technology Laboratory and President Obama’s recent pledge of US\$ 1.2 billion to the Advanced Research Projects Agency-Energy marks good progress in this arena. The literature to date has been

fairly US-centric, and there is a clear requirement/opportunity for countries outside the US to establish a stronger presence in this area.

The final key solution in this area is the efficient and effective dissemination of knowledge. The role of organizations such as the Institute of Electrical and Electronics Engineers will be integral to coordinating international smart grid efforts and helping share and establish best practices. The role of innovative professional networking sites which are dedicated to linking professionals within the cleantech sector should also not be underestimated as a forum for discussing and solving the key challenges facing the industry. Part of the solution will be effective impetus placed on those organizations which conduct pilots to contribute knowledge capital backs to the wider community. Levers such as fiscal stimulus conditions may be useful in this regard.

3.6 Addressing Cybersecurity Risks and Data Privacy Issues

Concerns over cybersecurity should be met with appropriate standards and legislation. Individuals should be satisfied that their personal data is protected and handled appropriately.

With increased computer and communications network interconnection comes the increased potential for cyber-attack. Information technology companies have been tackling similar security issues for more than 20 years, but the critical asset base in question makes this a considerable challenge. This is not a challenge limited to the larger utilities within an integrated system; all players must adhere to sufficiently high standards to withstand attack, as they all retain the potential of becoming a vector of vulnerability to the broader network.

NERC, with the support of NIST and EPRI, has been making some solid progress in the definition of cybersecurity standards. First and foremost, they are supporting utilities to identify critical assets and to apply risk-based assessments.²⁸ It is hoped that these standards will be rolled out industry-wide and provide a global benchmark. To date, the US has been most proactive in the creation of smart grid standards; it is imperative that Europe follow suit via the European Smart Networks programme to provide a unified international standard for Europe to serve what will potentially be a highly interconnected pan-European smart grid.

Standards will also need to be supported through new legislation; there are two US smart grid cybersecurity bills in the pipeline.²⁹ In alignment with this, utility executives will be expected to progressively establish expectations for cybersecurity performance and hold employees accountable. The systems will need to be rigorously tested on build and undergo continuous risk management. The challenges are not insurmountable and have been overcome with other critical systems – e.g. the global banking system – when treated with due care and attention.

There remains a valid concern regarding the way individuals' energy consumption data is used, both by the utility and by third parties. Such concerns recently held up a decision to mandate smart metering in the Netherlands.³⁰ The solution to such challenges will involve clear legislation around smart meter and smart grid data ownership and privacy, similar to how telecoms data is carefully managed and used today. Utilities, regulators and governments will need to give consumers confidence that



their usage data is being handled by authorized parties in an ethical manner. Such assurances will be the key when developing the public perception of these new technologies.

3.7 The Central Role of Cities in Catalysing Investment

Cities will play a pivotal role as catalysts for smart grid implementation, with some of the greatest needs and the greatest motivation. Several factors have been identified which highlight those cities likely to be early adopters.

Why Cities?

When looking at the global variation in smart grid drivers, it becomes apparent that cities will be integral in managing the transition to a smarter energy infrastructure and a functioning low-carbon economy. The city environment provides a prime location for smart grid investment. They are centres for electricity demand, investment and innovation; they are great starting points from which to pilot technologies in the move towards larger and larger scale roll-outs. Cities are looking for solutions; they have requirements to provide services which work towards national and internationally agreed targets on efficiency and carbon reduction goals (e.g. cities within the European Union striving towards a 20% reduction by 2020). Cities are also competing on a global stage for inward investment (to attract business and entrepreneurs), for public expenditure (for public funds to invest/create jobs, etc.), for residents (affluent, talented citizens) and for visitors (tourists and business travellers). Putting in place sustainable communications and electricity networks will be critical in maintaining a long-

term competitive edge. Rather than a piecemeal infrastructure upgrade approach, smart grid investments offer cities an integrated infrastructure upgrade methodology: optimization of operations (transmission and distribution networks), a drive for behavioural change (using less, cleaner energy) and the introduction of new technologies (smart grids, combined with smart meter and home/office automation) simultaneously.

On a purely environmental basis, it is imperative that cities engage in smart grids – 71% of emissions are generated by urban environments. Moreover, people continue to coalesce in urban environments, driving load growth and increases in city infrastructure – 50% of the world's population lives in cities today, and 70% of the global population is expected to live in urban environments by 2050.³¹

Smart grids could reach their greatest potential in urban environments, providing the backbone for a series of low-carbon technologies in the city environment, including the integration of distributed micro-renewables; biomass-based generation (using anaerobic digestion of organic waste); dynamic transport solutions; distributed sensing and control environments; interconnected smart building environments; electric vehicles charging infrastructure, etc. The municipality political construct has a privileged position to act as an integrator to help realize sustainability across multiple areas, often grid assets owners, with links to waste management companies, and building companies, and a role in transportation politics to bring together the disparate stakeholders and align them towards common goals such as CO₂ reductions.

Which Cities?

Cities will not be equal in their immediate amenability to a smart grid deployment or their relative capability to execute a smart grid strategy, the primary variables being policy and regulatory constructs, economics and consumer appetite. To identify the cities that are most likely to lead the change, a number of factors have been identified that, when they converge, will produce an environment that is primed for change. Both national and local factors will be at play.

National factors

- **Market structure:** The electricity market structure will be the key. Within a regulated and vertically-integrated market (e.g. in the US), the relative ease of aligning the different parts of the value chain to drive a common outcome will be significantly less complex. The alternative, a deregulated, liberalized market (e.g. United Kingdom, Germany), will have an increased need to motivate multiple, competing parties to drive in a common direction and to develop economic regulation which successfully rebalance who invests and who benefits.
- **Federalization:** Those countries which favour dissemination of the decision-making power will empower the local decision-makers (governors, mayors, etc.) to promote smart grid investment within their domain and equip them with the autonomy to strive ahead of the curve.
- **National ambition:** Some countries will target smart grids as a technology to excel and develop relevant intellectual property and skills to export globally. One example is South Korea, whose government drive has seen over-allocation of fiscal stimulus funds to smart grids, and the recruitment of over 100 personnel to a dedicated government department.

Local factors

- **Visionary leadership:** To engage in a task of this magnitude, the city will require bold and visionary leadership.
- **Political alignment:** The alignment of the political and decision-making authorities at the municipality level will be the key – the local government, the mayor, incumbent utility and the city council will need to step through the smart grid transition together. This was a key success factor in Boulder, Colorado, for example.
- **Municipal asset ownership:** It is much easier for cities to make smart grid decisions if the city owns the distribution assets.
- **Consumer appetite:** The city's appetite for change will also be fundamental. Those cities with environmentally aware citizens, who are open to new technology, will be able to move at a faster pace.
- **Specific goals and timelines:** An impending event or set of challenges can act as a catalyst for the decision-making. This could be a major political or sporting event or an impending election or contract renewal for utility concessions.

It is important to recognize that, even if cities operate as an impetus for smart grid implementation, they cannot act as single point implementations; this approach will never allow smart grids to reach a meaningful scale. Rather, they must sit within an integrated regional/national approach and commitment to a smart electricity system. It is also noted that, in some instances, visionary utilities may lead the way, e.g. as in Palo Alto, California.

4. Summary Recommendations

The acceleration of smart grid investment is pivotal to the creation of a low-carbon economy. It will require timely and definitive action across a range of stakeholders.

To achieve the successful acceleration of smart grid investment, it is necessary to raise awareness and understanding across all industry stakeholders. In parallel, it is imperative to support a transition from planning to implementation, establishing pragmatic policy and regulatory structures which drive the right behaviours and long-term outcomes across the industry.

The successful global acceleration of smart grid investment will be a central tenet of the transition to a lower-carbon economy. The benefits of smart grids (as described throughout this paper and crystallized in Figure 4) are persuasive and resonate across the full spectrum of stakeholders. To access this wealth of value, it will be necessary to ensure that the systemic industry structure is correct. Central to the required changes are two themes:

- **Regulatory refresh** – adapting utility regulatory regimes worldwide to provide clear profit motives to utilities to place value on energy efficiency; encouraging utilities to produce and deliver as efficiently and clean electricity as possible, without compromising security of supply
- **Public-private partnerships and societal value propositions** – a new era of collaboration is required across the utility industry and among government/policy-makers, accompanied by a move away from purely financial business cases to broader societal value propositions that demonstrate the benefits of smart grids to the general public

Despite the stated benefits outlined above, some policy-makers may still be hesitant to make what is undeniably a significant and definitive investment. However, it should be stressed that the potential costs of procrastination in making this transition are equally significant. Failing to have the appropriate backbone infrastructure is likely to put a brake on the integration of alternative low-carbon technologies. Maturing, clean technologies will struggle to shift from small-scale implementations to mass roll-out, for example PHEVs, and microgeneration. Without smart grids and the regulatory structures that support a shift in the utility retail operating model, it will be more difficult to deliver energy efficiency measures. The opportunities for industry to create new products and services, to develop a better understanding of their customers and to provide more jobs and economic uplift will be considerably curtailed.

The time for this action is now. Recent economic modelling by the Stern Review estimates that if action is not taken now, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever, rising to 20% of GDP or more if a wider range of risks and impacts is taken into account. In contrast, the costs of action now – reducing greenhouse gas emissions to avoid the worst impacts of climate change – can be limited to around 1% of global GDP each year.³²

To help progress the debate and to move towards this end goal, the section below provides a handful of key recommendations for each stakeholder group as a distillation of this paper's findings.

4.1 Government and Policy-makers

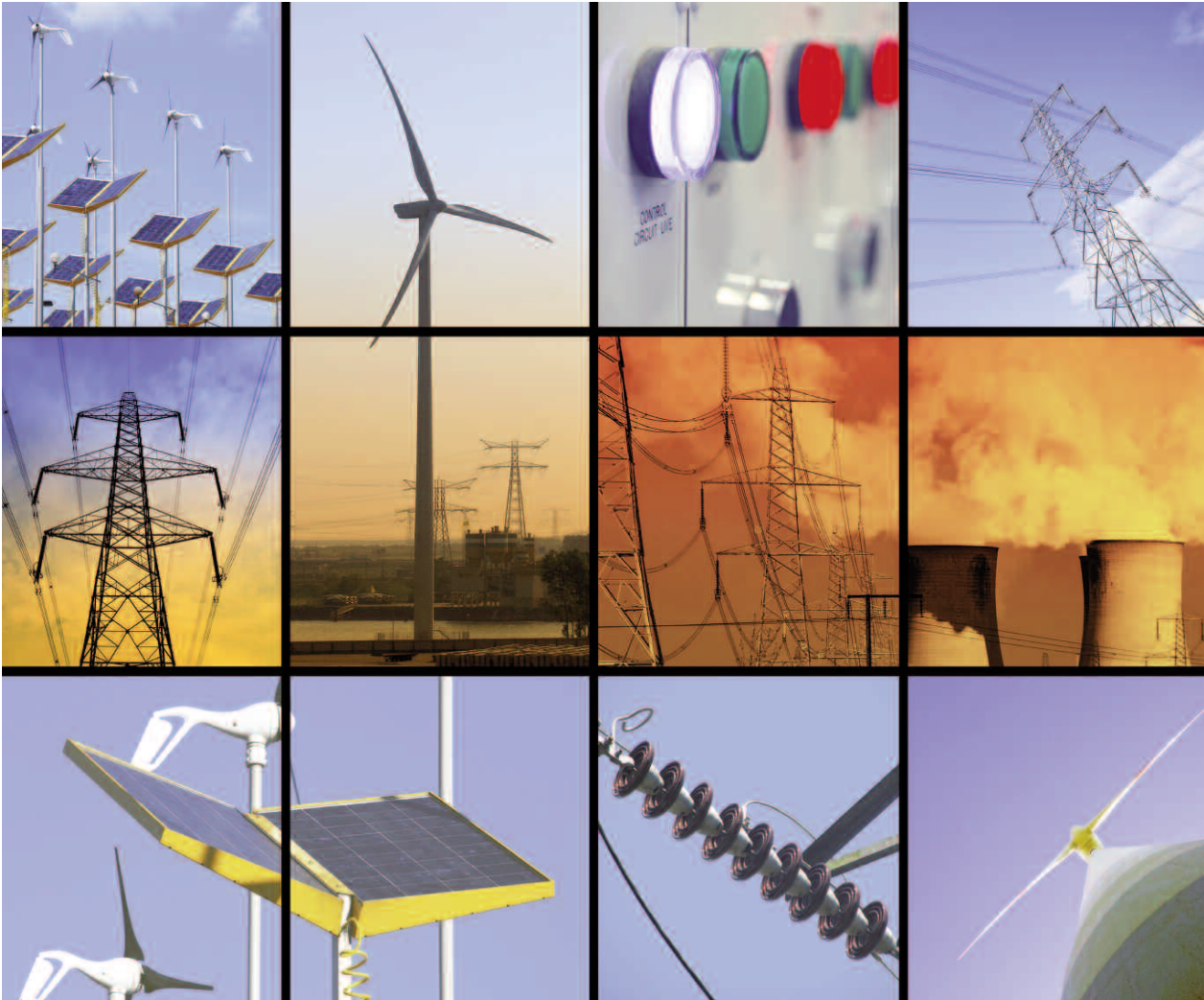
Policy-makers and governing bodies have a role to play at multiple levels to accelerate smart grid investment.

Trans-national

- Global policy forums will play a key role in establishing common smart grid standards and protocols that will remove industry uncertainty surrounding the risk of technology obsolescence and accelerate investment. A coordinated set of pilot projects with shared access to data and knowledge gained will help reduce delivery risk and therefore improve the value case for smart grids.
- Global climate change initiatives, such as the UN Climate Change Initiative (COP15), have an essential role to play in translating carbon reduction targets to action. Formalization of GHG reduction targets and liquid carbon markets will create a stronger platform for change and will help translate intangible carbon reduction externalities into financially quantifiable benefits.

National

- National policy-makers will need to rebalance the potentially competing objectives of climate change, security of supply, competitive markets and cost to the consumer. Clarity over these objectives and generation portfolio mix will help set the parameters for regulators and utilities to generate smart technology strategies.
- National statements of intent on the potential for this technology to achieve national carbon and security of supply objectives will help drive industry momentum and awareness. Statements of intent will allow vendors to invest in scaling up production which, in turn, will improve the value case for investment.



- Beyond statements of intent, national governments could potentially play an important role by developing regulatory frameworks and co-funding of pilot projects conducive to bringing down risks to investors.
- National governments are encouraged to look across their departmental portfolios to see the opportunity for economies of scale and scope regarding the deployment of smart technologies and national telecommunications infrastructure.
- National policy-makers can play a key role in encouraging utilities to stretch their thinking beyond standard smart metering deployments to consider smart grid and smart homes and offices.

Local

- Bold leadership by local government leaders can help catalyse the implementation of smart grids by drawing together critical stakeholders from utility companies and major industrial and commercial consumers.
- By setting a bold vision, strategy and roadmap for achieving energy efficiency and carbon substitution goals, local government can position cities at the forefront of the low-carbon economy, attracting high-value investment and boosting local GDP. The competition between major cities to house this next wave of clean technology companies is intense and will require integrated local strategies.

4.2 Regulators

Regulators will be responsible for designing and implementing relevant and workable regulatory frameworks and incentive structures that reflect the policy objectives set by politicians.

- Regulators will need to create regulatory frameworks that align the incentives of each participant in the energy value chain. In deregulated markets, this will require new economic frameworks that allocate risk and reward efficiently, create the right incentives and deal with asset stranding risk.
- In assessing the viability of utility investment plans, regulators should switch from a purely financial business case towards a broader set of measures that reflect the total societal value proposition.
- By shifting towards an output-based regulatory framework, regulators can translate the broader set of societal values into economic incentives and penalties that will encourage behaviour that aligns the needs of shareholders with societal needs.

4.3 Utilities

Utilities will be responsible for the majority of smart grid implementations and will need to reconcile the needs of society with shareholder needs.

- It is recommended that utilities adopt a more holistic approach to business case building. By widening this value proposition to a broader societal value proposition, they will build their regulatory case and demonstrate to their consumers the broader benefits case which will be realized over time.
- Utilities can reduce the risk of technology obsolescence by deploying smart technologies that are modular in design, forward compatible and interoperable.
- Conversations with government and regulators early in the process to identify potential for economies of scale and scope on multiple infrastructure investments (especially in telecommunications infrastructure) will deliver the greatest value to consumers.
- Utilities are recommended to undertake large-scale, broad capability pilots, and to measure the benefits as they are realized, adding concrete numbers and savings to what is to date a fairly difficult equation to quantify. They are encouraged to use this knowledge to refine future business case development.

- Utilities should consider strategies for transitioning from commodity service provision to a broader set of consumer value-added services early in the planning process. Early definition of this long-term strategy will help build in smart grid infrastructure that enables this transition (e.g. Home Area Networks and EV charging infrastructure).

4.4 Vendors

Technology vendors for all aspects of smart grids should not underestimate their role and should ensure that they engage in the smart grid debate.

- Vendors are encouraged to bring the wealth of their experience to the policy table and ensure their requirements are reflected in new regulatory regimes and global standards.
- Modular design, forward compatibility and interoperability of smart grid equipment will be a key driver of how fast utilities and consumers adopt the technology. Vendors are encouraged to move rapidly towards de facto standards to help utilities re-risk investments.
- As the industry moves rapidly towards standards for critical smart grid infrastructure, it is important that vendors continue to innovate with the end consumer in mind. The most successful vendors will create blended product and service offerings that make it easy for consumers to change their behaviour. For smart grids to move towards mass adoption, consumers will need to embrace the technology.

4.5 Customers

Customers have a critical role to play in the development of smart grids. By demanding and paying for cleaner and more flexible services (and being willing to switch supplier – where possible – to a supplier that offers more innovative, focused and value-added products), the business model will change by default. New entrants will come into the market with more customer-centric offerings and incumbent utilities will innovate and become more focused on how to create more flexible, efficient and value-added products and services. By demanding these services, the utility companies, politicians and regulators will understand that there is mileage in pursuing policies and frameworks that consumers want, and awareness will grow.

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Glossary

- **de facto standards** – A de facto standard is a standard (formal or informal) that has achieved a dominant position by legal enforcement.
- **de jure standards** – De jure standards are standards that have been approved by standard bodies, professional organizations, industry groups, a government body or other groups.
- **Decoupling** – In public utility regulation, decoupling refers to the disassociation of a utility's profits from its sales of the energy commodity. Instead, a rate of return is aligned with meeting revenue targets, and rates are trued up or down to meet the target at the end of the adjustment period. This makes the utility indifferent to selling less product and improves the ability of energy efficiency and distributed generation to operate within the utility environment.
- **Demand response** – This term generally refers to mechanisms used to encourage consumers to reduce demand, thereby reducing the peak demand for electricity. Demand response mechanisms enable consumer appliances to be shut off or cycled in response to electricity supply conditions, enabling electricity customers to reduce their consumption at critical times. Under conditions of tight electricity supply, demand response can significantly reduce the peak price and, in general, electricity price volatility. Since electrical systems are generally sized to correspond to peak demand (plus margin for error and unforeseen events), lowering peak demand reduces overall plant and capital cost requirements.
- **Distribution network** – The wiring from substations to customers is referred to as electricity distribution, following the historic business model separating the wholesale electricity transmission business from distributors who deliver the electricity to the homes.^[1]
- **Distributed generation** – generates electricity from many small energy sources. Currently, industrial countries generate most of their electricity in large centralized facilities, such as coal, nuclear, hydropower or gas powered plants. DG is another approach, using small-scale power generation technologies (typically in the range of 3 kW to 10,000 kW) to provide an alternative to or an enhancement of the traditional electric power system.
- **Output-based regulation** – regulation that rewards or penalizes specifically defined outcomes, such as carbon emissions, reliability improvements (in terms of customer minutes out), etc.
- **Plug-in hybrid electric vehicles** – a hybrid vehicle with batteries that can be recharged by connecting a plug to an electric power source. It shares the characteristics of both traditional hybrid electric vehicles (also called charge-maintaining hybrid electric vehicles^[1]), having an electric motor and a internal combustion engine, and of battery electric vehicles, also having a plug to connect to the electric grid (a plug-in vehicle).
- **Predictive monitoring** – extracts sensor information from equipment, control systems and business systems, and then uses sophisticated analytic models to predict equipment faults and sub-optimal performance long before the equipment fails. The system uses both historical and real-time data to make predictions about the future.
- **Stranded assets** – An asset that is worth less on the market than it is on a balance sheet due to the fact that it has become obsolete in advance of complete depreciation.
- **Smart grids** – Sensing, embedded processing and digital communications to enable the electricity grid to be *observable* (able to measure the states of all grid elements), *controllable* (able to affect the state of any grid element), *automated* (able to adapt and self-heal) and fully *integrated* (fully interoperable with existing systems and have the capacity to incorporate a diversity of energy sources).
- **Transmission network** – the bulk transfer of electrical power (or more correctly, energy), a process in the delivery of electricity to consumers. A power transmission network typically connects power plants to multiple substations near a populated area.
- **Vehicle-to-grid** – a system in which power can be sold to the electrical power grid by an electric-drive motor of a hybrid vehicle that is connected to the grid when it is not in use for transportation.^[1] Alternatively, when the car batteries need to be fully charged, the flow can be reversed and electricity can be drawn from the electrical power grid to charge the battery. Vehicle-to-grid can be used with such gridable vehicles – that is, plug-in vehicles (electric vehicles as battery electric vehicles or plug-in hybrid electric vehicles) with grid capacity.



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PERFECT POWER INSTITUTE™



Investing in Grid Modernization:

The Business Case for Empowering Consumers, Communities and Utilities

Prepared by John Kelly, Greg Rouse, Ruth Nechas and Amanda Wirth

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Online Access

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



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

Executive Summary

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

Smart Grid Costs and Benefits Summary

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

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

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

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

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

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1 Introduction

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

The projected benefits include:

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

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

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

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

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

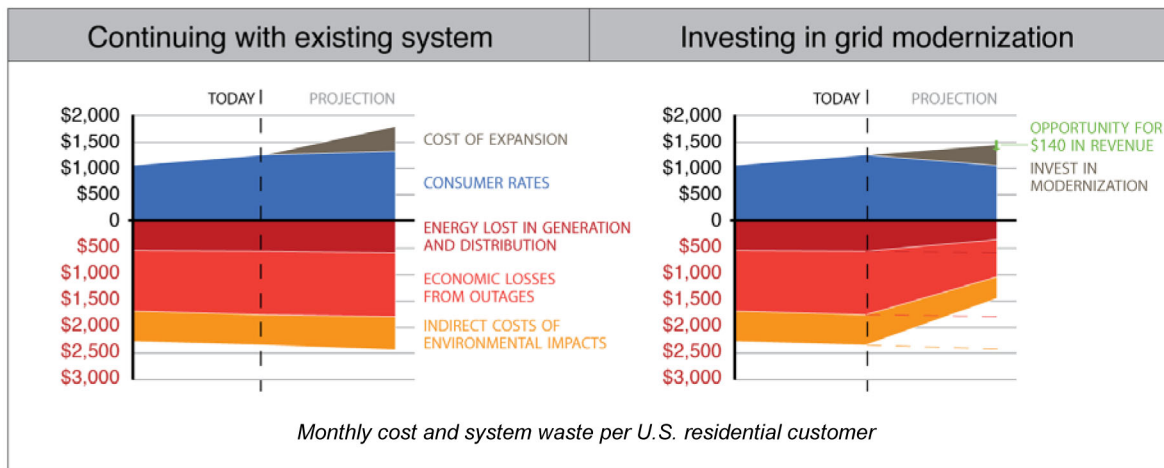


Table 1: Maintaining Electricity System Waste vs. Investing in Grid Modernization

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

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

1.1 PROJECT BACKGROUND

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

The Institute’s work and primary references include:

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

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

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

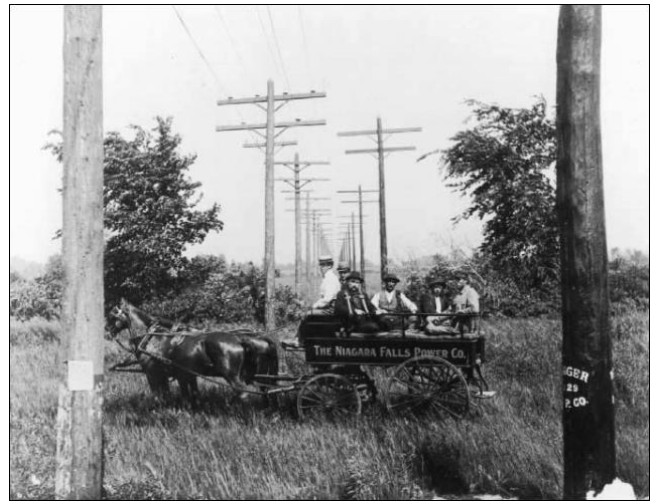
2 What Is Grid Modernization?

2.1 GOALS OF GRID MODERNIZATION

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

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

This requires a comprehensive transformation of the electricity system rules and design¹ that have remained essentially the same for the past century. In the photo on the right, you’ll notice the basic grid design from 1895 looks much as it does today, while primary modes of transportation have changed a great deal. The U.S. Department of Energy has said that our nation's competitiveness depends upon a modernization of our electricity system.



Line crew of Niagara Falls Power Co. in 1895.
Image 79-2142, Electricity & Modern Physics Collection, National Museum of American History, Smithsonian Institution, copyright, Smithsonian Institution

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

2.2 INVESTMENT CATEGORIES

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

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

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

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

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

2.3 SUCCESS CHARACTERISTICS

The Galvin Electricity Initiative has developed a comprehensive set of smart grid performance metrics³ and completed several prototypes of advanced smart grids.⁴ The Initiative has also completed Perfect Power prototypes and case studies that provide insight into effective and innovative smart grid design approaches.⁵ These efforts identified several key characteristics of effective smart grid programs and projects. Most important, early prototypes reveal that investment in the local distribution system provides the greatest impact on performance.

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

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

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

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

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

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

3 Electricity System Waste

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

- 1) **Building Conservation** — Today's building materials are relatively inefficient, resulting in high energy loss. Lawrence Berkeley National Laboratory (LBNL) estimated that building owners could save up to 30 percent through conservation.⁷ Assuming that 50 percent improvement in residential and commercial building efficiency is the theoretical limit, the total waste is \$150 billion annually.⁸
- 2) **Capacity Expansion** — Even though only about 50 percent of the current ~1,000 GW of generation and delivery system is utilized, additional capacity is projected to keep up with growth in peak demand — demand that continues to grow due to the lack of consumer response to daily swings in power demand. As a result, about 100 GW of new generation and delivery is called for and will be required to meet increasing peak demand. This is about 600 GW in unutilized capacity, representing waste of about \$60 billion, assuming generation and delivery costs of approximately \$3,700 per kW.
- 3) **Generation and Distribution Energy Efficiency** — Because fossil fuel has been relatively inexpensive to process, large power plants are not built to operate as efficiently as is technically feasible, and they waste about two-thirds of the fuel they consume.⁹ The power plants and lines that generate and carry power to our cities and towns have to send a large quantity of electricity a long way, losing thermal energy to the surrounding air and wasting up to another 7 percent of the electricity delivered.¹⁰ This equates to about 25 quadrillion BTU or \$70 billion annually at \$3/mmBTU in wasted fuel.
- 4) **Power Reliability and Quality** — Our power lines are out in the open where they fall prey to weather, animals and accidents. When the power lines are damaged, utilities, consumers and businesses pay for the resulting repairs and economic losses. Electricity interruptions also cause injuries and deaths, resulting from lost power to life-safety equipment, heating and cooling, as well as causing fires and electrocutions. Consumer impacts include flooded basements due to inoperable sump pumps, spoiled food and increased cost of goods due to business downtime and lost productivity. The total estimated annual cost is about \$150 billion annually.¹¹
- 5) **Environmental Impacts** — The electric power sector is a major contributor to carbon, sulfur, mercury and other hazardous emissions. The full human health and environmental

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

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

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

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

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

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

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

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

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

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

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

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

3.1 WHO PAYS FOR SYSTEM WASTE?

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

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

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

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

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

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

To further exacerbate the situation, a significant portion of the existing customer's delivery charge is invested in system expansion and higher voltage system improvements, even though LBNL reported that the majority of power interruptions are not caused by the transmission or area-wide high-voltage distribution system but are instead due to events that affect the local low-voltage distribution system.¹⁴ Essentially investments are being diverted from improvements that would reduce interruptions to support new customers. For example, PEPco in response to widespread power interruptions, announced a Comprehensive Reliability Enhancement Plan¹⁵ that allocated 60 percent of the targeted \$320 million in improvement spending to system expansion.

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

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

3.2 NAPERVILLE — ELIMINATING WASTE AND TARGETING INVESTMENT

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

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

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

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

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

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

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

4 Investment and Benefit Prerequisites

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

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

- 50 percent or more improvement to interruption duration/frequency and power quality measures;
- 15 percent reduction in peak demand-reducing costs associated with system expansion;
- 50 percent reductions in inefficiency, economic losses and waste, such as time spent repairing a grid that continuously fails due to recurring lightning, ice and wind storms, as well as indirect costs associated with power interruptions and poor power quality;
- 50 percent improvement in generation efficiency and environmental performance. Examples include source energy intensity (mmBTU consumed per MWh delivered), carbon intensity (lbs. of CO₂ equivalent emitted/MWh delivered) and solid waste landfilled (percent solid wastes recycled); and
- Measurable improvement in distribution system efficiency — MWh delivered to customer meters/MWh entering the system.

The benefit estimates assume the following market reforms:

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

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

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

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

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

5 Investment Costs of Grid Modernization

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

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

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

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

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

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

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

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

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

5.1 CLEAN POWER SUPPLY INVESTMENT

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

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

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

5.2 POWER DELIVERY INVESTMENT

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

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

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

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

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

- 1) The deployment of innovative technologies that allow substations to automatically isolate faults, restore service and re-route power. Today, utilities rely on manual fuses — like the old ones in homes — that open on a fault and must wait for utility crews to install a new one. Instead of everyone being served by the substation and thousands of residents losing power, with smart switches only a few hundred are out of service, and power to the rest of the residents is automatically restored;
- 2) The use of circuit looping with smart switches dispersed along looped circuits. Looping provides residents with power from two directions and smart switches sense and isolate faults to a very small area (i.e., a few homes). Instead of entire neighborhoods being in the dark due to a tree falling on a line, only a few customers are impacted;
- 3) Undergrounding cables to dramatically improve reliability and power quality, reduce repair costs, reduce tree-trimming costs and improve esthetics. Today's electricity system, for the most part, is exposed on overhead lines and poles. Very often when a storm rolls through a city, the power is knocked out. The typical response is to cut down all of the trees that threaten the power lines. Unfortunately, as cities try to become greener, they are planting more trees, resulting in a futile cycle of residents planting trees and utilities cutting them down. It is time for the electricity sector to invent more economical ways of moving the grid underground or to ground level;
- 4) The optimization of tap settings that reduce transformer efficiency losses. The savings can be reinvested into reliability or advanced meter upgrades; and
- 5) Advanced software, automation and control systems that can coordinate market pricing with end-use devices and utility system conditions to optimize reliability, power quality, efficiency and asset utilization. This network of technology is sometimes referred to as a master controller.

5.2.1 Transmission and Area Distribution

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

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

Table 4: Transmission and Area Distribution Investments

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

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

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

5.2.2 Local Distribution System or Microgrid Improvements

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

Table 5: Distribution Improvement Costs

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

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

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

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

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

5.2.2.1 Local Substation Automation

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

5.2.2.2 Circuit Loops with Smart Switches

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

The following assumptions were used to estimate additional costs for:

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

5.2.2.3 Undergrounding Local Cables (Lower Voltage)

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

While undergrounding cables makes practical sense, cost is cited as an issue. However, as technology and methods for undergrounding improve, this objection diminishes. Trenchless technology, lower repair costs and improved reliability all must be factored in when determining the true rate of return of undergrounding. The costs will drop even further when this work is coordinated with other municipal sewer and street projects. Some cities are offering to install

conduits with every major infrastructure project for use by the utility in the future. The cost for undergrounding cables is estimated at \$1,000,000 per local circuit for 50 percent of the EPRI-estimated 460,000 circuits. Based on a 15-year rollout, this would cost each household about \$50 per resident per year.

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

5.3 END-USE INVESTMENT

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

5.3.1 Local Clean Power Supply — Distributed Energy

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

5.3.2 Smart Meters

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

5.3.3 Home Automation

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

6 Benefits of Grid Modernization

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

Table 6: Summary of Estimated Annual Savings per Residential Household

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

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

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

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

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

Table 7: Baseline Electricity Consumption and Spending^{21,22}

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

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

6.1 DIRECT BILL SAVINGS

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

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

The savings will come from:

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

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

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

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

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

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

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

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

6.1.1 Electricity Consumption Savings

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

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

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

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

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

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

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

Table 8: Adjusted Average Consumption

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

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

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

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

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

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

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

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

6.1.3 Avoided New Capacity Costs

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

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

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

6.1.3.1 Avoided New Generation Capacity Costs

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

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

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

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

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

Table 9: Estimate of Avoided New Generation Capacity Costs

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

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

6.1.3.2 Avoided New Delivery Capacity Costs

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

Table 10: Estimate of Avoided New Delivery Capacity Costs

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

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

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

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

6.1.4 Improved Generation Efficiencies

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

Table 11: Generation Efficiency Savings

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

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

6.1.5 Reduced Transmission and Distribution Losses

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

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

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

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

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

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

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

6.1.6 Reduced Operating Costs

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

6.2 INDIRECT SAVINGS

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

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

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

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

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

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

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

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

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

6.2.1 Improved Reliability and Power Quality

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

LBNL analyzed the assumptions made in prior estimates and developed their own framework for assessing the cost of interruptions.³⁸ LBNL estimated the economic losses of unreliable electricity to be approximately \$80 billion per year, but it could be as high as \$130 billion per year, not including power quality events. Reports by EPRI and the U.S. Department of Energy have estimated the cost of electricity interruptions at between \$30 billion and \$400 billion per year³⁹ — quite a large range.

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

- Average Indirect Cost Savings⁴⁰ = \$75 billion per year
- Average Annual kWh Consumed⁴¹ = 3,710 billion kWh
- Total number of residential customers = 125 million

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

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

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

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

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

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

Table 14: Interruption Cost Indirect Savings

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

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

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

6.3 FUTURE REVENUE POTENTIAL

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

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

6.3.1 Revenue for Providing Electricity and Ancillary Services

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

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

6.3.2 Emission Reduction Credits

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

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

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

Table 15: Emissions Reduction Revenue/Savings

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

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

6.4 PUBLIC HEALTH, SAFETY AND HOMELAND SECURITY

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

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

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

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

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

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

6.4.1 Direct Contact with Power Lines

In terms of safety, utilities track and report deaths and injuries of workers in accordance with standards set forth by the Occupational Safety and Health Administration (OSHA). This agency also tracks deaths related to workers from other industries that come in contact with power lines. The U.S. Department of Labor’s Bureau of Labor Statistics reports that about 100 people each year die from contact with power lines and more than half are not from the utility industry. However, this does not include non-occupational deaths from contact with power lines. Tables 16 and 18 provide a summary of work-related, electricity-related deaths from 1992 to 2003.⁴⁴ Table 17 reveals that contact with overhead lines is a leading cause of non-electricity worker deaths, totaling 630 over 12 years.

Table 16: Worker Death Statistics by Trade

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

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

Table 17: Worker Death Statistics by Cause

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

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

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

6.4.2 Outage Related Deaths and Injuries

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

The Names Behind the Numbers

March 27, 2008 — Cleveland, Ohio

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

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

February 4, 2009 — Galesburg, Ill.

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

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

June 2, 2009 — Allegheny, Pa.

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

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

July 25, 2010 — Lancaster County, Pa.

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

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

January 16, 2011 — San Bernadino, Calif.

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

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

7 Conclusions

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

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

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

“Technology has no inherent value; technology defines its value by what result it achieves in terms of improving the customer experience.”

— *Robert Galvin,*
as CEO of Motorola

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

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Appendix A: Achieving Perfect Reliability

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

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



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

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

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

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

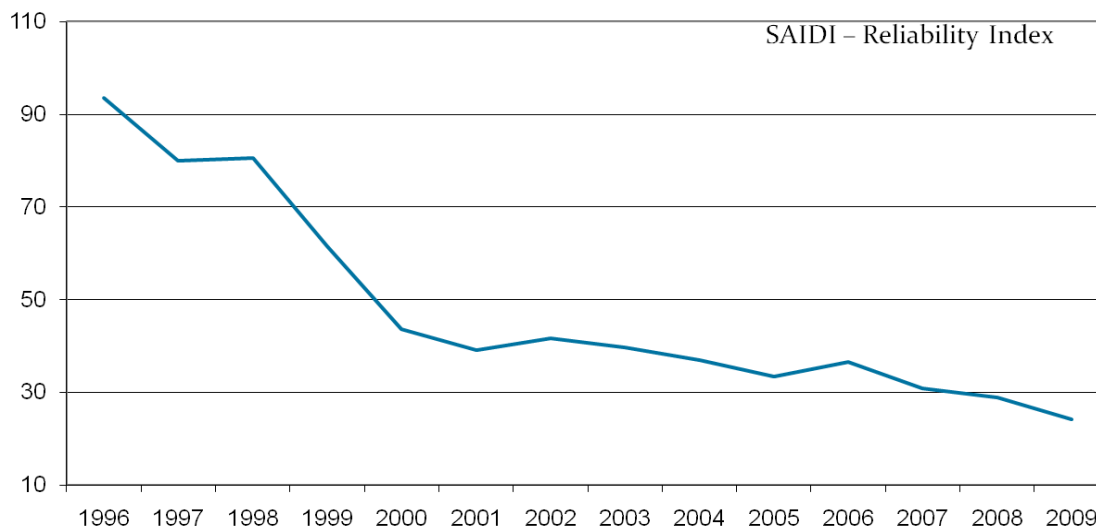
Table 19 shows the current status of Naperville’s smart grid program and Figure 1 shows Naperville’s SAIDI since 1996. As this data shows, dramatic improvements were made and were accomplished by applying continuous improvement methods to establish a new, more reliable design philosophy (i.e., underground,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

Table 18: Naperville Smart Grid Process

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

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

Figure 1: Naperville SAIDI Improvements



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

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

Appendix B: Zero Direct Carbon Emissions on the IIT Campus

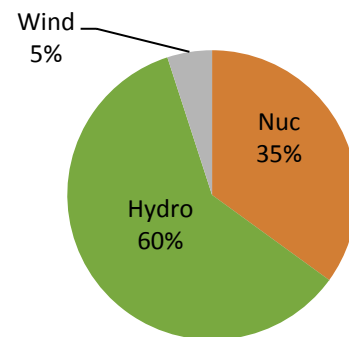
In 1996, Bob Galvin challenged the Illinois Institute of Technology (IIT) to strive for perfection in the delivery of their campus-wide electricity. This included competitive prices, no power failures and no carbon emissions. IIT's initial reaction was simple and direct: The task was impossible. Yet,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

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

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

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

Figure 2: IIT Fuel Mix



Appendix C: Waste Calculations

BUILDING INEFFICIENCY

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

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

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

⁴⁷ Ibid.

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

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

⁵⁰ Ibid.

WASTED CAPITAL

PLANT UTILIZATION CALCULATIONS	
According to the EIA, ⁵¹ the total U.S. generation capacity is 1,010 GW. ⁵² Total electricity consumption is about 3,800 million MWh. This equates to an average plant utilization of about 40 percent or 400 GW.	
System capacity	1,010,000 MWh
Total system delivered	3,800,000,000 MWh
System capacity factor	$3,800,000,000 \text{ MWh} / (1,010,000 \text{ MW} * 8760) \text{ hours} = .43$

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

WASTED DISTRIBUTION CAPITAL CALCULATIONS	
The very peaky load causes enormous waste in our T&D system as well. At \$1,500/kW ⁵⁴ , this waste is costing consumers \$25 billion a year.	
Wasted generation	$.50 * 1,010,000 \text{ MWh} = 505,000 \text{ MWh} = 505,000,000 \text{ kWh}$
Plant costs	\$1,500/KW
Term	30 years
Total costs	$\$1,500/\text{kWh} * 505,000,000 \text{ kWh} = \$757,500,000,000$
Annual costs	$\$757,500,000,000 / 30 \text{ years} = \$25,250,000,000/\text{yr}$

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

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

⁵³ Assumed average cost of generation per kilowatt hour.

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

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

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

⁵⁵ Assumed average cost of generation per kilowatt hour.

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

GENERATION AND DISTRIBUTION ENERGY INEFFICIENCY

ELECTRICITY SUPPLIED CALCULATIONS			
The annual electricity sales for each sector can be found in the <i>Annual Energy Outlook 2010</i> , Table A8: Electricity Supply, Disposition, Prices and Emissions.			
Sector	Sales (million MWh) ⁵⁷	Sales (mmBTU) ⁵⁸	Sales (QBTU) ⁵⁹
Residential	1,380	4,709,940,000	4.71
Commercial	1,350	4,607,550,000	4.61
Industrial	980	3,344,740,000	3.34
Total	3710	12,662,230,000	12.66

GENERATION AND DISTRIBUTION EFFICIENCY CALCULATIONS	
The total fossil fuel consumption can be found in the <i>Annual Energy Outlook 2010</i> , Table A2. We find that 36.6 QBTU of electricity is consumed while only 12.66 QBTU actually reaches end-users. This reveals an electric system efficiency of 35 percent.	
Total fossil fuel consumption for electricity	36.6 QBTU ⁶⁰
Electricity supplied	12.66 QBTU
Electricity system efficiency = (12.66 QBTU/36.6 QBTU)*100	35 percent

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

⁵⁸ 1MWh = 3.413 mm BTU.

⁵⁹ 1mmBTU = 1 billion QBTU.

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

GENERATION AND DISTRIBUTION EFFICIENCY WASTE CALCULATIONS			
When generating and transmitting electricity, thermal losses are inevitable. The farther power is sent, the more energy is lost. This equates to about 24 quadrillion BTU or \$70 billion annually in wasted fuel.			
Sector	100% Efficiency	Baseline Efficiency 35% (Sales mmBTU/.35)	Waste at \$3/mmBTU
Residential	4,709,940,000	13,456,971,428	$\$3/\text{mmBTU} * (13,456,971,428 \text{ mmBTU} - 4,709,940,000 \text{ mmBTU}) = \$26,241,094,284$
Commercial	4,607,550,000	13,164,428,571	$\$3/\text{mmBTU} * (13,164,428,571 \text{ mmBTU} - 4,607,550,000 \text{ mmBTU}) = \$25,670,635,713$
Industrial	3,344,740,000	9,556,400,000	$\$3/\text{mmBTU} * (9,575,902,857 \text{ mmBTU} - 3,351,566,000 \text{ mmBTU}) = \$18,634,980,000$
Total			\$70,546,709,997

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

POOR POWER RELIABILITY AND QUALITY

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

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

EMISSIONS WASTE COST

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

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

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

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

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

Appendix D: Benefit Calculations

ELECTRICITY CONSUMPTION SAVINGS

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

CONSUMPTION SAVINGS CALCULATIONS	
Because definitive data has not been found that analyzes the permanence of energy savings over an extended period of time from home automation, this research paper makes the conservative assumption of 10 percent savings based on information from several automation companies.	
Supporting Data	
<p>Vantage⁶⁷ claims that in the average home, 40 percent of all electricity used to power home electronics is consumed while they are turned off, and dimming all or most of your lights just 25 percent saves 5 percent in overall energy consumption.</p> <p>Cortexa⁶⁸ claims their automation products can save homeowners 30 percent on their energy bills.</p> <p>Magnum Energy Solutions⁶⁹ conducted a study at a Wyndham Hotel that shows that rooms using their Venegy automation system consumed 33 percent less energy than rooms without these controls.</p> <p>Lutron⁷⁰ reported 40 to 60 percent reductions to lighting loads in the commercial sector, without adversely affecting productivity.</p>	
10 percent reduction in electricity consumption	.10 * 11,040 kWh = 1,104 kWh
Consumption savings per customer	1,104 kWh * \$0.114/kWh = \$125.86

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

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

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

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

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

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

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

DYNAMIC PRICING, TIME OF USE, SHIFTING PEAK DEMAND

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

AVOIDED NEW GENERATION COSTS

GENERATION CAPACITY	
<p>If, through grid modernization, consumers could permanently reduce their peak demand by 10 percent, the U.S. peak demand could be reduced by about 100 GW.⁷² This would more than offset the projected 100 GW of new demand by 2025. Furthermore, in a restructured generation market, the private sector bears the cost of capital for new generation.</p>	
Current generation	1,010 GW ⁷³
Projected new generation	100 GW⁷⁴

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

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

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

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

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

⁷⁵ Assumed average cost of generation per kilowatt hour.

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

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

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

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

⁷⁸ Ibid.

⁷⁹ Ibid.

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

AVOIDED NEW DISTRIBUTION COSTS

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

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

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

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

⁸³ Ibid.

⁸⁴ Ibid.

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

GENERATION INEFFICIENCIES

ELECTRICITY SUPPLIED CALCULATIONS			
The annual electricity sales for each sector can be found in <i>Annual Energy Outlook 2010</i> , Table A8: Electricity Supply, Disposition, Prices and Emissions.			
Sector	Sales (million MWh) ⁸⁶	Sales (mmBTU) ⁸⁷	Sales (QBTU) ⁸⁸
Residential	1,380	4,709,940,000	4.71
Commercial	1,350	4,607,550,000	4.61
Industrial	980	3,344,740,000	3.34
Total	3710	12,662,230,000	12.66

GENERATION AND DISTRIBUTION EFFICIENCY CALCULATIONS	
The total fossil fuel consumption can be found in the <i>Annual Energy Outlook 2010</i> , Table A2. We find that 36.6 QBTU of electricity is consumed while only 12.66 QBTU actually reaches end-users. This reveals an electric system efficiency of 35 percent.	
Total fossil fuel consumption for electricity	36.6 QBTU ⁸⁹
Electricity supplied	12.66 QBTU
Electricity system efficiency = (12.66 QBTU / 36.6 QBTU) * 100	35 percent

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

⁸⁷ 1MWh = 3.413 mmBTU.

⁸⁸ 1mmBTU = 1 billion QBTU.

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

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

SAVINGS PER HOUSEHOLD CALCULATIONS	
This calculation assumes that 50 percent of the commercial and industrial savings are passed on to consumers.	
Sector	Savings passed on to households
Residential	\$13,710,876,549
Commercial	$.5 * \$13,412,814,015 = \$6,706,407,008$
Industrial	$.5 * \$9,736,709,436 = \$4,868,354,718$
	\$25,285,638,275
Total savings per household	$\$25,285,638,275 / 125,000,000 \text{ customers}^{90} = \mathbf{\$202}$

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

REDUCED TRANSMISSION AND DISTRIBUTION (T&D) LOSSES

AVERAGE T&D COSTS CALCULATIONS		
The current costs of transmission and distribution are included in Table A8 of EIA's <i>Annual Energy Outlook 2010</i> .		
Service category	Price per KWh ⁹¹	Price per MWh ⁹²
Transmission	\$0.007	\$7.00
Distribution	\$0.024	\$24.00
Total	\$0.031	\$31.00

GENERATION COSTS CALCULATIONS		
The cost of generation per sector is determined by subtracting the T&D cost from the retail price of electricity.		
Sector	Retail price per MWh ⁹³	Generation cost per MWh
Residential	\$112.60	\$112.60 - \$31.00 = \$81.60
Commercial	\$103.60	\$103.60 - \$31.00 = \$72.60
Industrial	\$68.30	\$68.30 - \$31.00 = \$37.3

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

⁹² 1MWh = 1,000 kWh.

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

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

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

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

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

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

RELIABILITY AND POWER QUALITY

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

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

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

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

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

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

EMISSION REDUCTION CREDITS

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

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

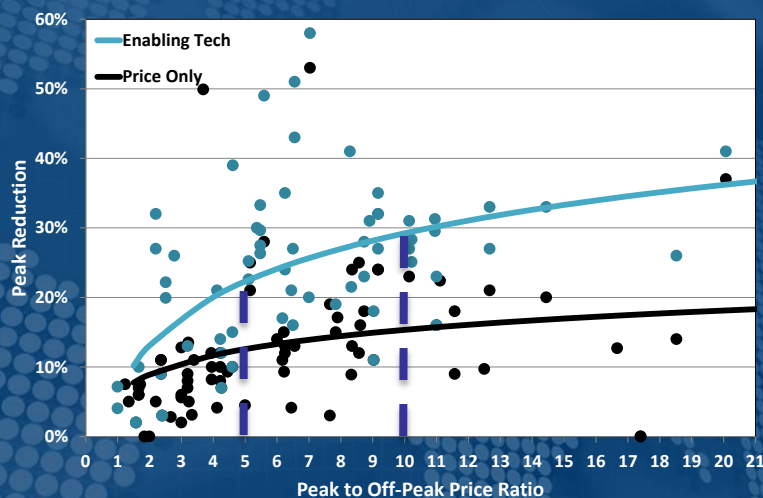
¹⁰⁰ U.S. Energy Information Administration, U.S. Department of Energy. (2010). *Annual Energy Outlook 2010*, Tables A1 – A20.

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

EMISSIONS SAVINGS CALCULATIONS			
The savings shown below assume a 30 percent reduction in emissions based on improvements in conservation, generation efficiency and reductions in generation emissions.			
Sector	Sales (million MWh) ¹⁰²	Outage cost savings per sector	Savings per household
Residential	1,380	$\$5.45 * 1,380,000,000 = \$7,521,000,000$	$\$7,515,550,000 / 125,000,000$ customers = \$60
Commercial	1,350	$\$5.45 * 1,350,000,000 = \$7,357,500,000$	$.5 * \$7,368,400,000 / 125,000,000$ customers = \$29
Industrial	980	$\$5.45 * 980,000,000 = \$5,341,000,000$	$.5 * \$5,351,900,000 / 125,000,000$ customers = \$21
Total			\$110

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

Consistency of Results in Dynamic Pricing Experiments – Toward a Meta Analysis



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DistribuTECH
San Diego, California
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Agenda

- 1. The Issue**
- 2. Defining “Consistency”**
- 3. Dynamic Pricing Experiments**
- 4. Determining the Consistency of Results**
- 5. Conclusion**

The Issue

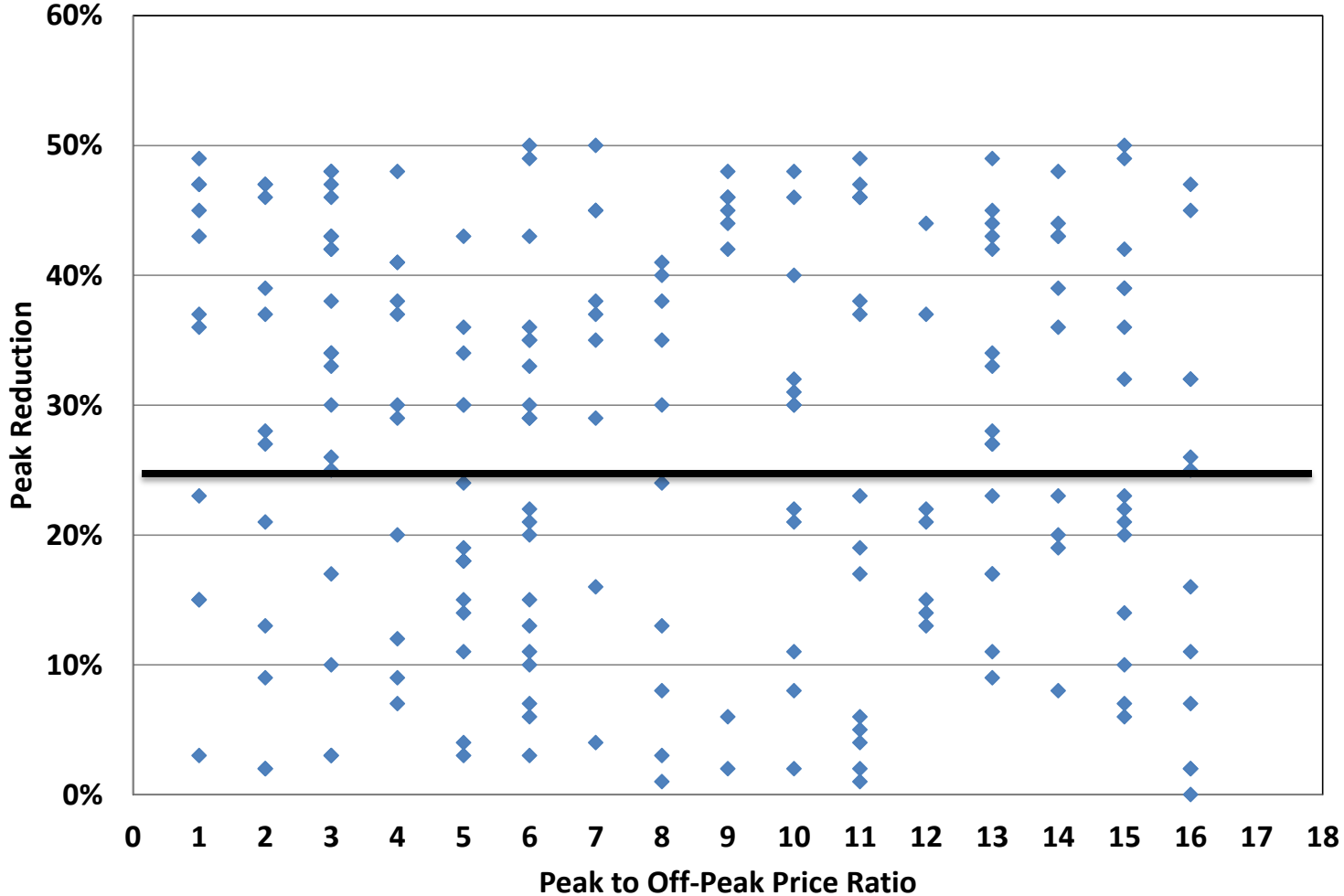
It is important to examine the results of dynamic pricing experiments for consistency

A full-blown test of consistency will require the analyst to normalize for differences in experimental design, in particular for the selection of participants

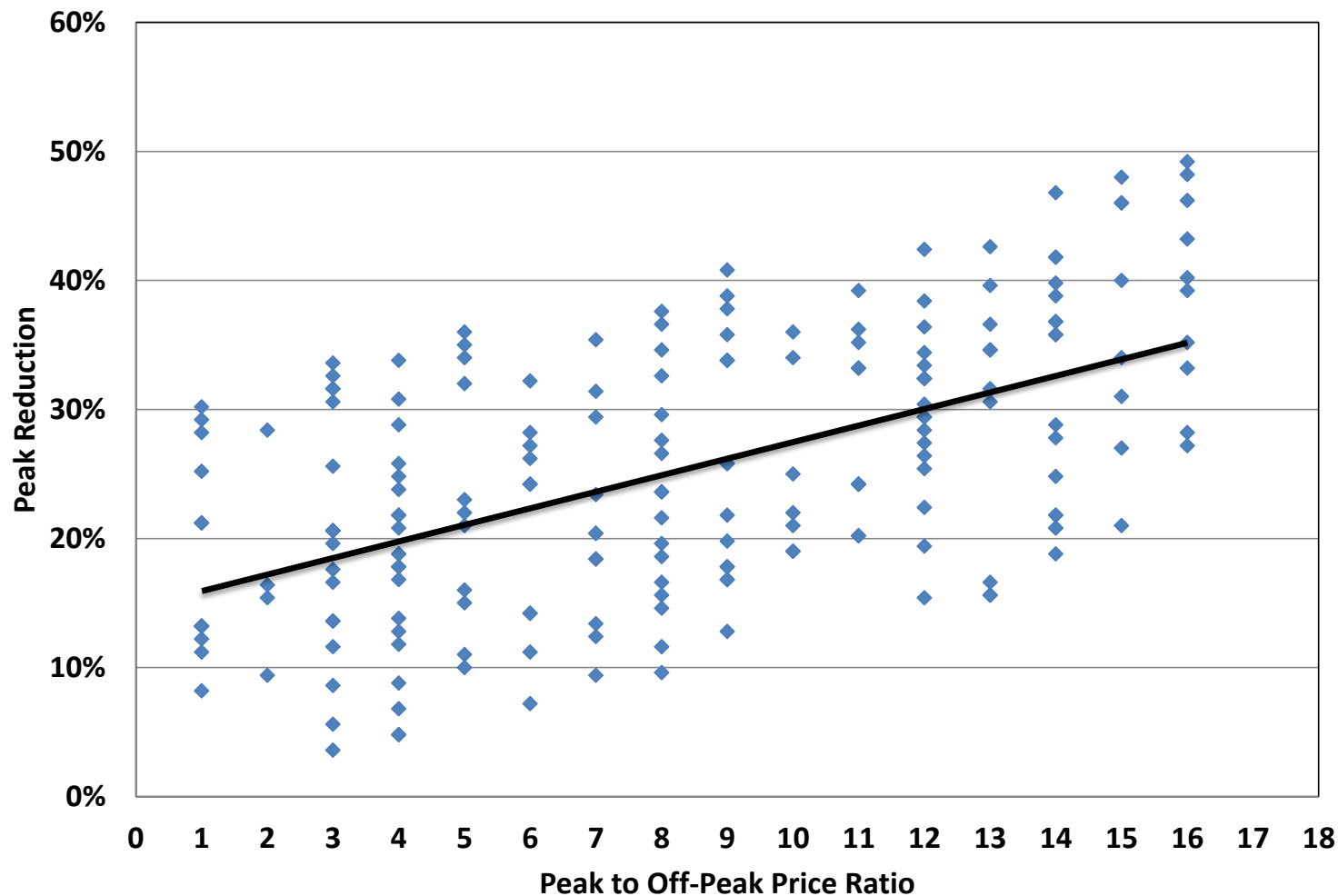
This would require that primary data on individual customers be collected across all the experiments, allowing the execution of a full blown meta analysis

In this presentation, we present some initial findings on consistency using the aggregate results from 31 dynamic pricing experiments, as a first step toward a meta analysis

If there was no consistency in results, we would get this type of random display



If there was consistency, we would see something like this



To test the hypothesis of consistency, we rely on results from 31 experiments (containing 144 treatments) spanning 7 countries in 4 continents

No.	Experiment	Location	Year	Rates	Enabling Technologies	Number of Treatments
1	Ameren Missouri	Missouri	2004, 2005	CPP	CPP w/Tech	4
2	Anaheim CPP Experiment	California	2005	CPP	Not tested	1
3	Automated Demand Response System (ADRS)	California	2004, 2005	TOU, CPP	TOU w/ Tech, VPP w/ tech	4
4	Baltimore Gas & Electric (BGE)	Maryland	2008, 2009, 2010	CPP, PTR	CPP w/ Tech, PTR w/ Tech	17
5	BC Hydro	Ontario, Canada	2008	TOU, CPP	Not tested	8
6	California Statewide Pricing Pilot (SPP--Pacific Gas & Electric, San Diego Gas & Electric, Southern California Edison)	California	2003, 2004	TOU, CPP	CPP w/ Tech	4
7	Commonwealth Edison (ComEd)	Illinois	2010	TOU, CPP, PTR	Not tested	3
8	Connecticut Light & Power (CL&P)	Connecticut	2009	TOU, CPP, PTR	TOU w/ Tech, CPP w/ Tech, PTR w/ Tech	18
9	Consumers Energy	Michigan	2010	CPP, PTR	CPP w/ Tech	3
10	Country Energy	Australia	2005	CPP	CPP w/ Tech	1
11	GPU	New Jersey	1997	TOU	TOU w/ Tech	2
12	Gulf Power	Florida	2000	CPP	CPP w/ Tech	1
13	Hydro Ottawa	Canada	2006	TOU, CPP, PTR	Not tested	6
14	Idaho Power	Idaho	2006	TOU, CPP	Not tested	2
15	Integral Energy	Australia	2007, 2008	CPP	CPP w/ Tech	2

The 31 experiments (concluded)

No.	Experiment	Location	Year	Rates	Enabling Technologies	Number of Treatments
16	Irish Utilities ¹	Ireland	2010	TOU	TOU w/ Tech	16
17	Istad Nett AS	Norway	2006	TOU	Not tested	1
18	Mercury Energy	New Zealand	2008	TOU	Not tested	3
19	Newmarket Hydro	Ontario, Canada	2007	CPP	CPP w/ Tech	1
20	Newmarket Tay Power Distribution	Ontario, Canada	2009	TOU	Not tested	1
21	Oklahoma Gas & Electric (OG&E)	Oklahoma	2010	TOU, VPP	TOU w/ Tech, VPP w/ Tech	14
22	Olympic Peninsula Project	Washington	2007	CPP	CPP w/ Tech	1
23	Pacific Gas & Electric (PG&E) (Full scale rollout)	California	2009, 2010	TOU, CPP	Not tested	4
24	Pepco DC	District of Columbia	2008, 2009	CPP, PTR	CPP w/ Tech, PTR w/ Tech	4
25	Public Service Electric and Gas Company (PSE&G)	New Jersey	2006, 2007	TOU, CPP	TOU w/ Tech, CPP w/ Tech	8
26	Pudget Sound Energy	Washington	2001	TOU	Not tested	1
27	Sacramento Municipal Utility District (SMUD)	California	2011	CPP	CPP w/ Tech	2
28	Salt River Project	Arizona	2008, 2009	TOU	Not tested	2
29	San Diego Gas & Electric (SDG&E)	California	2011	PTR	PTR w/ Tech	2
30	Sioux Valley Energy (SVE)	South Dakota	2011	CPP	Not tested	4
31	Smart Community Pilot Project in Kitakyushu	Japan	2012	VPP	Not tested	4
					Total	144

1. Run by the Commission for Energy Regulation (CER)

Types of experimental treatments

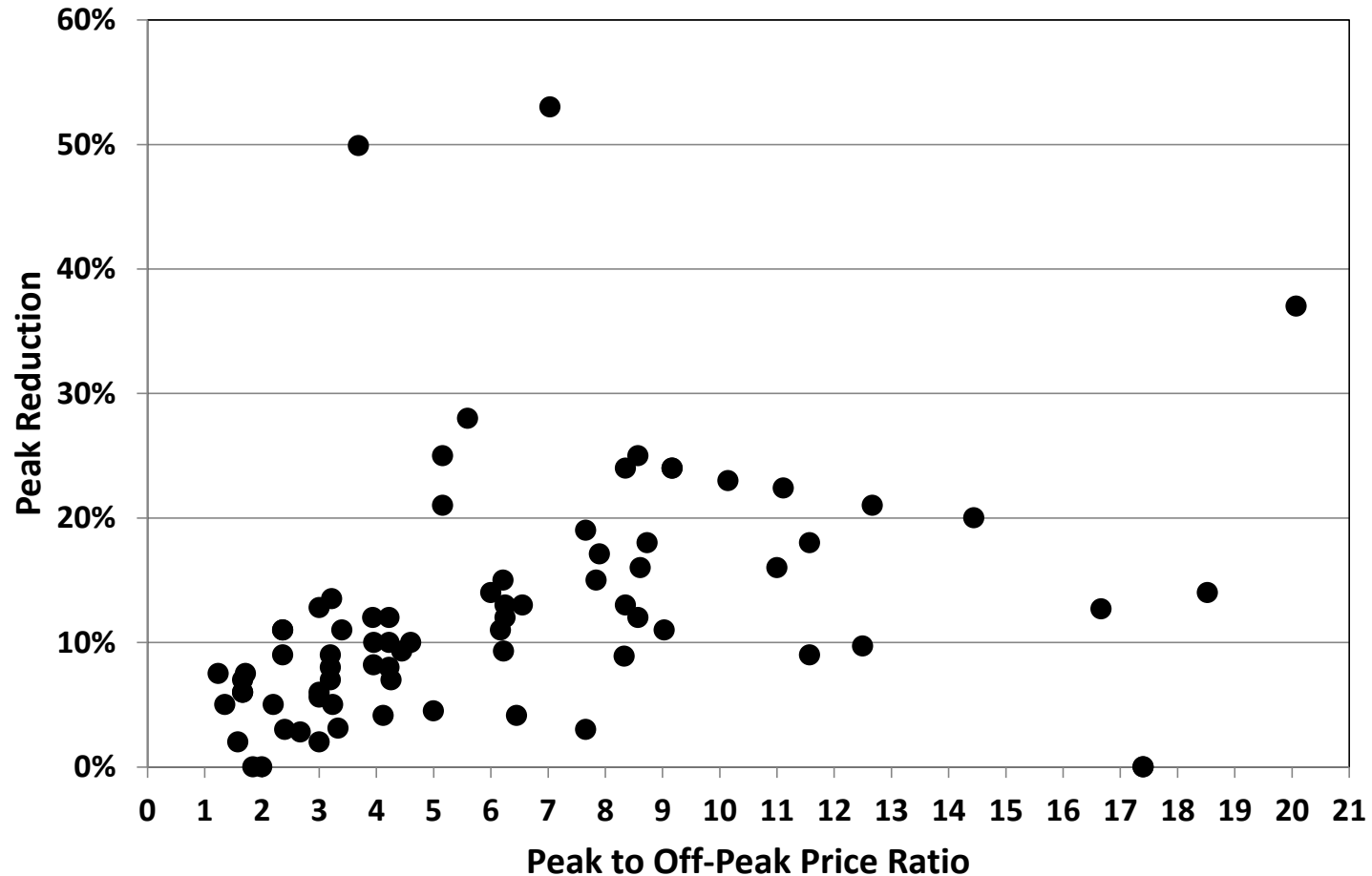
Pricing-only experimental treatments

- ◆ Time-Of-Use (TOU)
- ◆ Critical Peak Pricing (CPP)
- ◆ Peak Time Rebate (PTR)
- ◆ Variable Peak Pricing (VPP)

Price + Enabling Tech experimental treatments

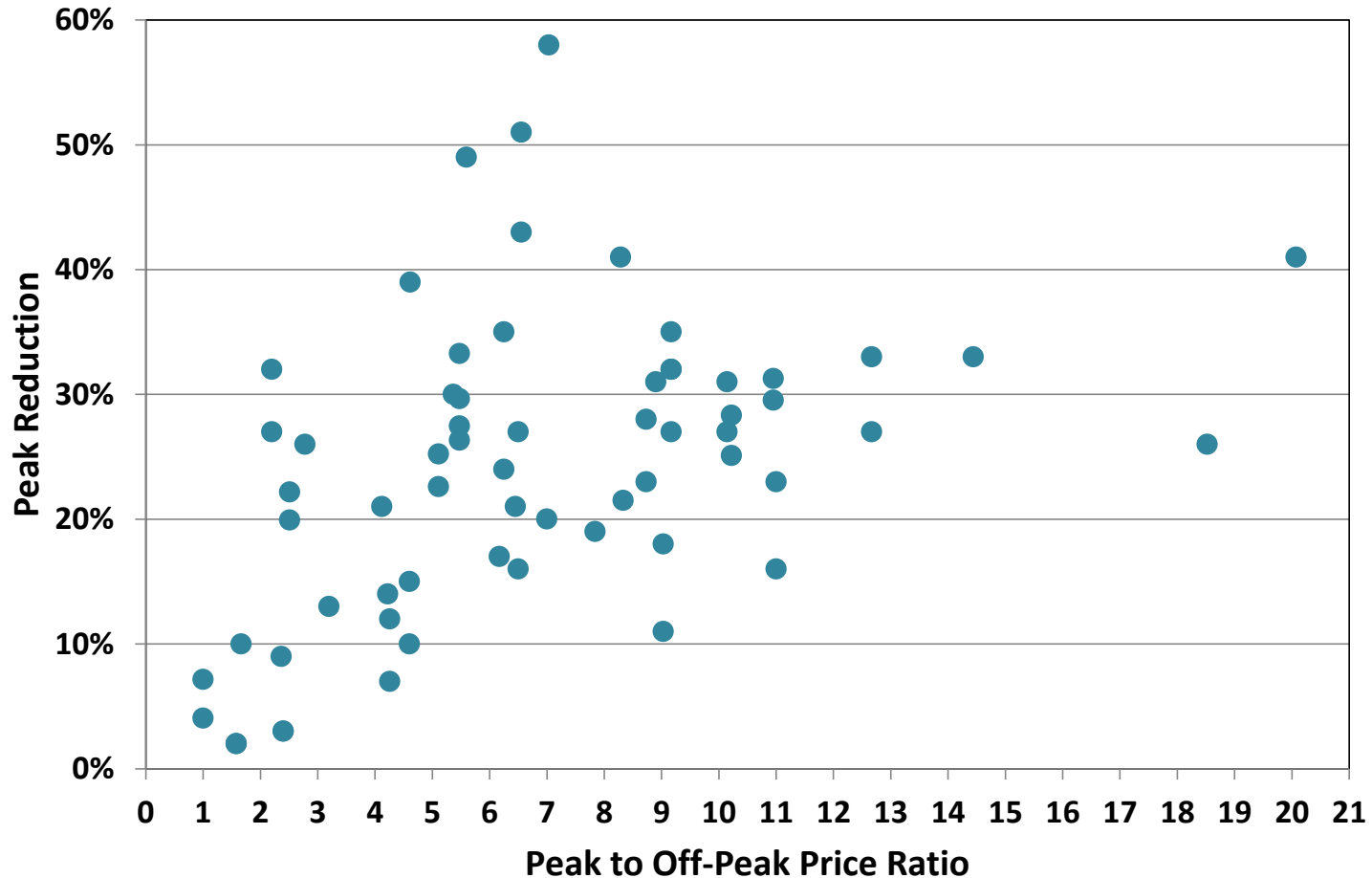
- ◆ Enabling technologies such as programmable thermostats and in-home displays (IHDs) can be offered with dynamic rates

The 79 price-only treatments fall into a tight pattern



Note: Data points from Japan and PSE&G are omitted because of extremely high price ratios

The 65 treatments involving price and enabling technologies have a more diffuse pattern



Note: One data point from PSE&G is omitted because of its extremely high price ratio

We estimate the following regression model

Coefficient	Regression
Ln(Price Ratio)	0.0401 *** (0.0118)
Ln(Ratio_EnablingTech)	0.0603 *** (0.0086)
Intercept	0.0612 (0.0205)
Adjusted R-Squared	0.3806
F-Statistic	44.94
Observations	144

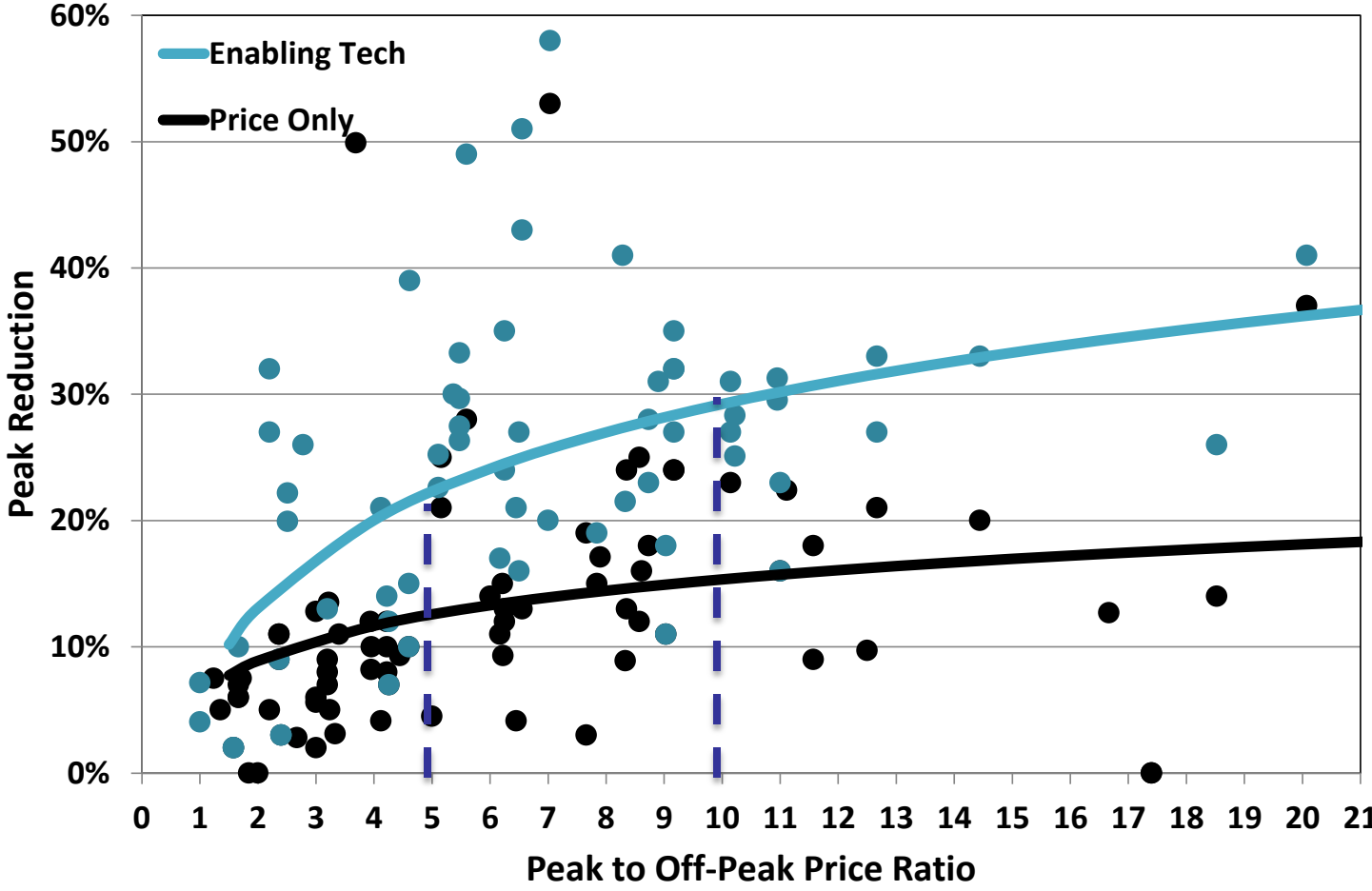
Standard errors are shown in parentheses below the estimates

*** $p \leq 0.001$

** $p \leq 0.01$

* $p \leq 0.05$

The analysis yields two “arcs of price responsiveness”



The arcs can be used to make simple predictions

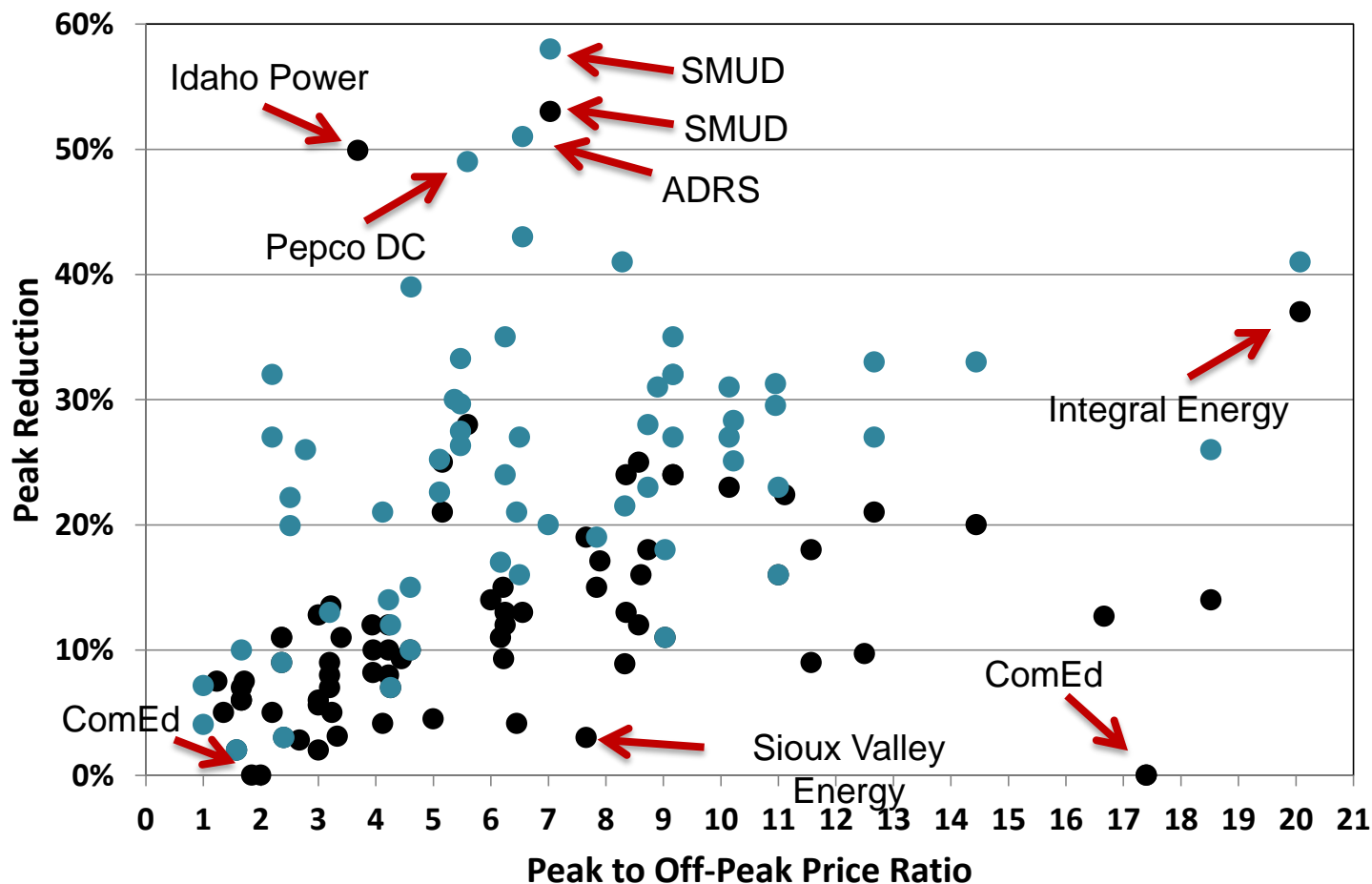
Peak to Off-Peak Price Ratio = 5

- ◆ Pricing-Only: ~12.6% peak reduction
- ◆ Pricing + Tech: ~22.3% peak reduction

Peak to Off-Peak Price Ratio = 10

- ◆ Pricing-Only: ~15.3% peak reduction
- ◆ Pricing + Tech: ~29.2% peak reduction

Of the 31 experiments, seven yield outliers that warrant further research



Note: Experiments with extremely high impacts (~50% for pricing+tech and >~40% for pricing-only) or extremely low impacts (~0%) are categorized as outliers

Conclusions

The amount of demand response increases as the peak to off-peak price ratio increases but at a diminishing rate

- ◆ Enabling technologies boost price responsiveness even more

There are many drivers of demand response besides the price ratio

- ◆ Length of peak period
- ◆ Number of pricing periods
- ◆ Climate and appliance ownership
- ◆ How the rate was marketed to customers
- ◆ How customers were selected into the experiment

Because we were unable to control for these factors in this initial analysis, there are some outliers along the arc of price responsiveness

Even then, the surprising amount of consistency in the results shows that utilities and policymakers can be confident in successfully achieving load reductions from dynamic pricing programs

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Dr. Faruqui has developed hourly, daily and monthly demand models to estimate the impact of dynamic pricing in pilot and full-scale modes of operation. He has managed the design and evaluation of large-scale dynamic pricing experiments in California, Connecticut, Florida, Illinois, Maryland and Michigan.

He has been working on rate design issues since the beginning of his career and his early work summarizing the results of 14 time-of-use pricing pilots is cited in Professor Bonbright's text on public utility rates.

His research on pricing issues has been cited in publications such as *The Economist*, *The New York Times*, and *USA Today* and he has appeared on Fox News and National Public Radio.

The author, co-author or editor of four books and more than 150 articles, papers and reports on efficient energy use, he holds a Ph.D. in economics and an M.A. in agricultural economics from The University of California at Davis, and B.A. and M.A. degrees from the University of Karachi.

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