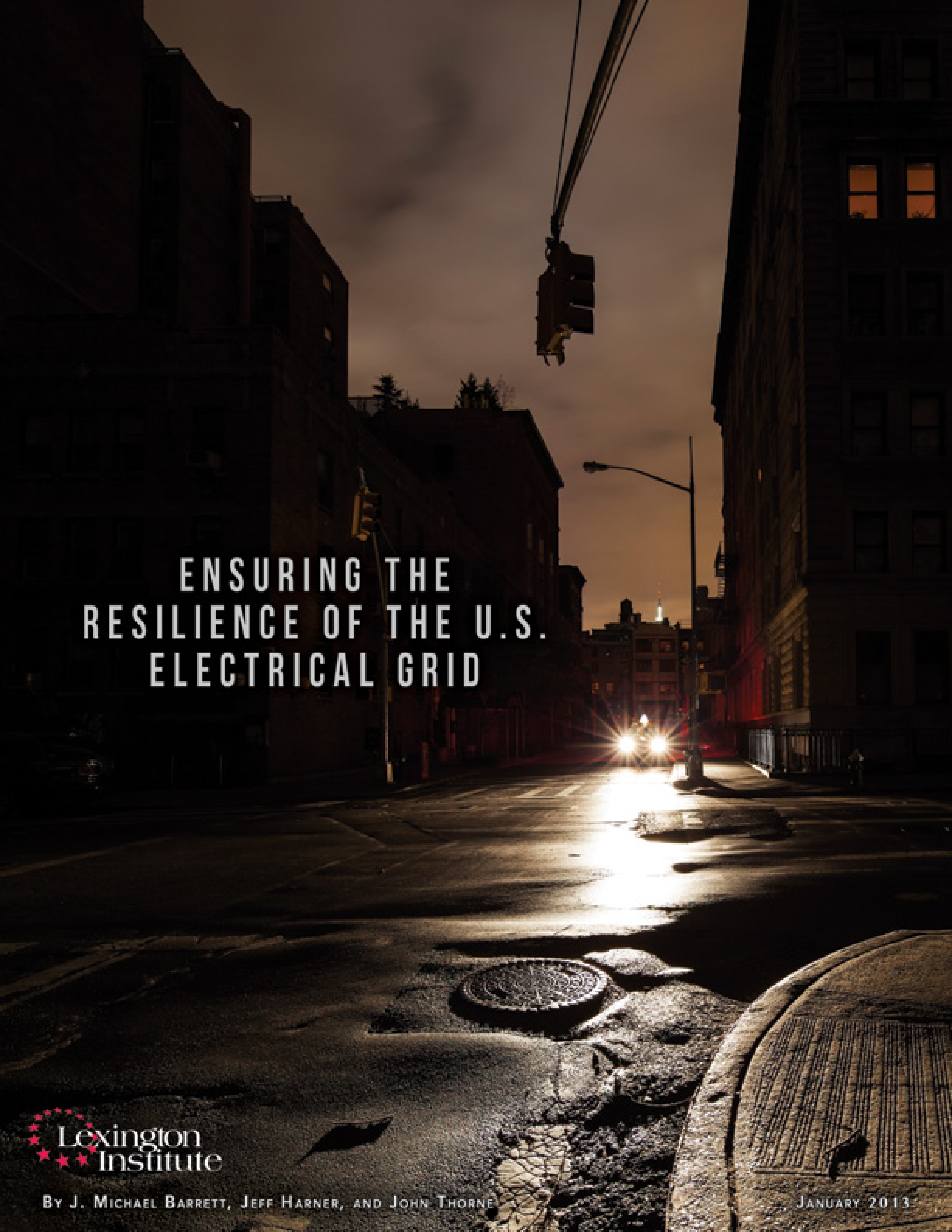

ENSURING THE RESILIENCE OF THE U.S. ELECTRICAL GRID

Lexington Institute

By J. Michael Barrett, Jeff Harner, and John Thorne

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EXECUTIVE SUMMARY

The North American power grid is a modern engineering marvel, and yet at the same time it is increasingly a system facing great risk of being disrupted by adverse events. Nearly all of the critical infrastructure elements upon which Americans rely are dependent upon the grid's persistent supply of widely available and relatively affordable electrical power.

Many of the most important ongoing grid modernization and infrastructure improvements currently underway are focused on the development of a so-called "smart grid" that can (among other facets) better track power usage, measure it against traditional usage patterns, and identify anomalies. But long-term solutions must manage shared risks so that solutions do not slip between segments and sectors where governance gaps exist and direct responsibilities are unclear.

As aging infrastructure is replaced and updated, embedding resilience within the electrical grid requires three main categories of investment: 1) managing and meeting overall demand to help avoid an adverse event; 2) expanding alternatives or substitute systems before and after an event; and 3) enabling rapid reconstitution if and when a disruption does occur.

Five specific strategies for minimizing the impacts of disruptions are discussed:

- Redundant Capabilities;
- Robust Supplies of Standardized, Interchangeable Spare Parts;
- Substitute Systems;
- Implementing Peak Demand Management;
- Incorporating Strategic Priorities for Diversifying Critical Capabilities.

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INTRODUCTION

According to the U.S. Department of Energy, "Our century-old power grid is the largest interconnected machine on Earth, so massively complex and inextricably linked to human involvement and endeavor that it has alternately (and appropriately) been called an ecosystem."[1]

The grid today utilizes over 360,000 miles of transmission lines, including approximately 180,000 miles of high-voltage lines, connecting to over 6,000 power plants.[2]

> *Since 1982, growth in peak demand for electricity – driven by population growth, bigger houses, bigger TVs, more air conditioners and more computers – has exceeded transmission growth by almost 25% every year.*
>
> *- U.S. Department of Energy*

This system has been an important economic driver for more than 100 years, although over just the past decade and, in very visible fashion, Americans of nearly all ages, backgrounds and income levels have borne witness to an amazing increase in electricity consumption at the individual user level. This increase is primarily driven by high standards of living and disposable income that afford widespread use of multiple personal electric devices such as laptop computers, cell phones, and internet modems, each of which is nearly always on and/or constantly recharging. There are also several million fully electric on- and off-road vehicles that are served by the same electrical power grid, with the number increasing every day.

And yet even though we have such tremendous reliance on our persistent access to widely available and relatively affordable electrical power, all too few of us understand how the power generation, transmission, and delivery systems work and – crucially – how severe the consequences would be if the grid were to fail us for any prolonged period.

Those consequences – which could include food and fuel shortages, massive transportation and telecommunications disruptions, and a lack of access to bank machines or use of credit cards – could radically affect individuals, businesses, and governments over a prolonged period. Understanding how the system works is the first step in determining if, how and to what degree to address significant risks. It is worth examining how our national power grid actually works today.

1 *The Smart Grid: An Introduction*, U.S. Department of Energy, Washington, DC, December 2008.

2 U.S. Department of Energy, Large Power Transformers and the U.S. Electric Grid, June 2012, p. 5.

THE ESSENTIAL ROLE OF THE NORTH AMERICAN ELECTRICAL POWER GRID

The role of the electrical grid in our economy is so significant that it was named as the "greatest engineering achievement of the last century" by The National Academy of Engineering.[3] Indeed, without the electrical grid much of the amazing industrialization and economic progress of the past century would not have been possible. This central role as a truly modern miracle and essential piece of the economy is evident because the electrical grid serves as the physical connection between the supply of broader global energy resources and the energy demands of end-users of electricity here in the U.S., whether those users are individuals, businesses, or Federal, state and local governments.

Without our 'always-on' power grid we would have to rely upon smaller and less reliable systems or significantly less efficient and less widespread micro-generation.

At the same time, the grid is an essential element of the interdependent transportation, communication, water and other necessary services infrastructures upon which so much of our economy relies because it serves as the primary and preferred power supply for such critical elements as fuel pumps, traffic signals, the air traffic control system, and radio and cell phone towers.

Beyond routine operations, however, in practical terms electricity plays an even more fundamental role in preserving the life and safety of all Americans. Indeed, the role of electricity in sustaining normal daily operations during crises can hardly be overstated, reaching across all the necessities of modern life (e.g., enabling transportation, 24-hour business operations, running hospital equipment, and powering First Responder dispatch systems) as well as numerous conveniences (e.g., air conditioning, cellular telephone networks, and refrigeration for food).

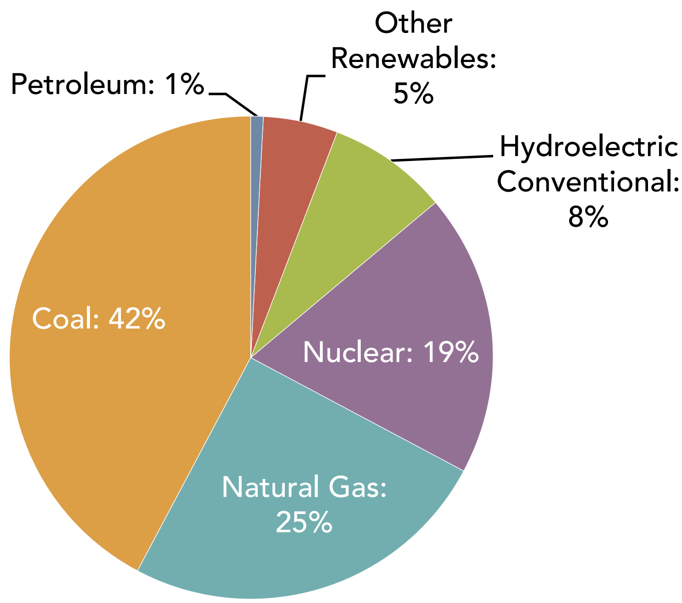
This truth is all the more relevant during prolonged disruptions and any period when weather or other additional challenges are also a factor in sustaining life, such as extreme high or low temperatures. As a result, the energy sector as a whole – and electrical power in particular – represents a highly interdependent and very valuable and critical segment of our overall economy.

HOW IT WORKS: ELECTRICAL POWER GENERATION & DISTRIBUTION

Power plants produce electricity from the conversion of primary energy sources such as coal, water, natural gas, oil, and nuclear power into electricity that is then distributed via a system of transformers, high voltage transmission lines, and distribution lines.

[3] Joel Achenbach, "The 21st Century Grid: Can we fix the infrastructure that powers our lives?", *National Geographic*, July 2010.

Fuel Sources of US Electricity Generation, 2011



The key processes of the electricity segment involve four major areas:

1. Inputs: In order for coal to be used by power plants to create electricity it first must be mined and transported to the power plants, often via rail car. Hydroelectric sources are often controlled through dams that regulate the flow of water into the plant, but as with coal, oil and natural gas supply chains involve production (i.e., extraction), shipped via tanker or pipeline to a refinery, and then transported by truck, ship or pipeline to the power plant. The material for nuclear plants must also be mined, processed and transported. The linkages across sectors are thus apparent from the very beginning of the electricity production process.

2. Generation: Power is generated by approximately 5,800 major power plants and numerous other smaller generation facilities across the country.

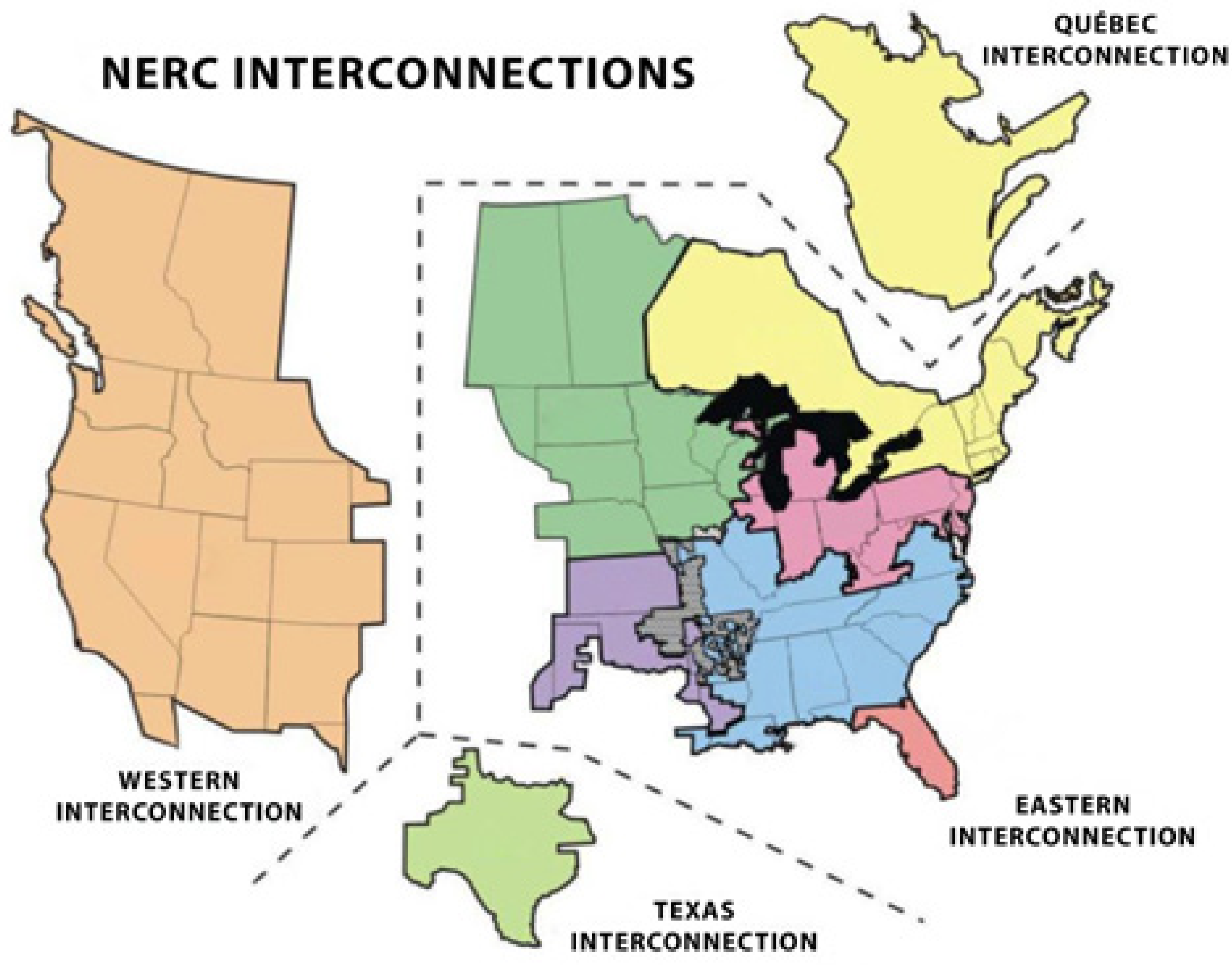
3. Transmission: As power is generated it cannot be stored, the grid lacks the capability to store it. Rather it must be immediately transmitted to local substations along a network of high voltage wires connecting the site of generation to the population centers that need the power. The U.S. has a fragmented distribution network, however, because within the mainland U.S. three sectors comprise the so-called "national grid" described below.

4. Distribution to End Users: The end users of electricity include practically all public and private sector entities, including emergency services, government facilities, private sector manufacturing and other businesses, and the general public. While some high volume electricity users have specialized substations on their own premises, generally the retail electrical system relies on local/regional power companies that connect to the national grids described above via substations and then deliver electricity the final few miles to the end users.[4]

[4] American Society of Civil Engineers, "Failure to Act: The Economic Impact of Current Investment Trends in Electricity Infrastructure", April 26, 2012, p.4.

OUR ELECTRICAL POWER "GRID" IS REALLY FOUR (BARELY) INTERCONNECTED GRIDS

While the power generation and delivery process described above seems reasonably straightforward, in practice many economic, geographic and historical practicalities complicate the interoperability of our "national power grid", as manifested in the fact that the U.S. and Canada are served not by a single grid as much as by four inter-locking regional grids, the Eastern, Western, Texas, and Quebec systems, as depicted below:



Source: www.energy.gov

Significantly, while these regional grids are technically connected to a small degree they are not in fact integrated in terms of the ability to share large amounts of power. As a result, in the event of a prolonged disruption to any of the single discrete segments of the North American power grid today it would be both very desirable and essentially technically impossible to have the remaining grids share their power across and into the affected grid. There are some pilot projects looking to test the feasibility of making these systems more interoperable, but the capability is not there at this time.

While this does have the potential benefit of limiting any cascading failure from taking out the entire nation's power supply, that will be of little comfort to any of the tens of millions of individuals and businesses that may be affected for weeks or months until the problems in any given affected regional grid are remedied.

BOLSTERING SYSTEMIC RESILIENCE

According to the American Society of Civil Engineers, "If future investment needs are not addressed to replace and upgrade our nation's electric generation, transmission and distribution systems, then costs will be borne by both households and businesses. These costs may occur in the form of higher costs for electric power, or costs incurred because of power unreliability, or costs associated with adopting more expensive industrial processes".[5] These shared costs require concerted preventive and mitigation efforts.

As a result of all these costs – and the growing risk profile when the above hazards are considered in isolation and collectively – it is clear the modernization of our infrastructure and shift towards a "smart grid" to increase our awareness of what is happening and why is well deserving of our attention and interest. Marshaling the willpower to positively impact the system will require a national conversation and should be focused on using the principles of systemic resilience to ensure the continuing operation of the system regardless of the nature of the threat or hazard.

This approach of focusing on resilience includes investments in basic solutions such as interchangeable parts for major capital equipment as well as new technologies to enable the storage of energy to use as surge capacity during disruptions and increased real-time awareness of what is happening in and through the power grid with increased use of "smart" devices and better tracking of energy demand, delivery and usage patterns.

Despite the significant and growing risks described above there does not seem to be sufficient political awareness to support the kinds of broad-based infrastructure investments that would genuinely secure and protect our ability to ensure continued easy access to electrical power for the coming decades. This includes multibillion dollar investments in everything from refreshed generation capacity and new power plants to redundant distribution networks using new, modular parts to smart meters that can identify and help isolate disruptions and anomalies. Responsibility for paying for these investments, between energy consumers and taxpayers, must be established.

While estimates of the costs to develop these solutions range from several hundred billion to $1.4 trillion over a decade, this cost is put into perspective when considering the estimated $119 billion of productivity losses each year due to power disruptions and outages – losses that may be rising significantly as the severity of each incident and the likelihood of those incidents both increase. Regardless, the discussion is because while the impacts are widespread they are also cumulatively significant. Infrastructure development and other long-lead

[5] American Society of Civil Engineers, "Failure to Act," p.42.

changes will take years or decades to implement, meaning if we are to address them the public discourse that could lead to such improvements needs to start, and start soon.

RISKS TO THE ELECTRICAL POWER GRID ARE PERSISTENT …AND GROWING

For all of the marvel the electric grid's engineering achievement merits, it is increasingly a system facing great risk. Part of this is merely due to the age of many of its essential components, for as the American Society of Civil Engineers (ASCE) has noted,

> Altogether, our nation's electric energy infrastructure is a patchwork system that has evolved over a long period of time, with equipment of widely differing ages and capacities. For example, about 51% of the generating capacity of the U.S. is in plants that were at least 30 years old at the end of 2010. Most gas-fired capacity is less than 10 years old, while 73% of all coal-fired capacity is 30 years or older. Moreover, nationally, 70% of transmission lines and power transformers are 25 years or older, while 60% of circuit breakers are more than 30 years old".[6]

The organization assigned the U.S. energy infrastructure a grade of "D+" on its most recent assessment in 2009.[7] The Report Card for America's Infrastructure went on to describe congestion in transmission and distribution systems that complicates routine maintenance and exacerbates risks of systemwide failures.[8]

MEASURING THE RISKS

Measurements of risk are generally described as a function of both the potential severity of an adverse event and the likelihood of such events taking place. This binary set of factors highlights the key relationship between not only if an event will happen but also how bad the impacts would be if it did, and enables effective risk-based decisions about how to reduce risk by helping distinguish frequent but relatively minor events from those that may be less frequent but would be significantly more important if they did occur.

While severe weather and other disruptive incidents provide ample evidence of the increased likelihood of events taking place, it is actually the increased severity that creates the more significant impacts, for in today's hyper-complex and ever more inter-dependent world the impact of any given event can cascade well beyond its immediate vicinity. This reality was demonstrated on March 11, 2011 when a powerful tsunami hit Japan's nuclear power generation capabilities in Fukushima and resulted in power and other disruptions that affected global manufacturing. As one analyst noted,

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6 American Society of Civil Engineers, "Failure to Act," pgs. 18-19.

7 American Society of Civil Engineers, *Report Card for America'sInfrastructure*, 2009.

8 *Ibid.*

> The quake and tsunami damaged or closed down key ports, and some airports shut briefly. This disrupted the global supply chain of semiconductor equipment and materials. Japan manufactures 20% of the world's semiconductor products, including NAND flash, an indispensable electronic part of Apple's iPad. Japan also supplies the wings, landing gears and other major parts of Boeing's 787 Dreamliner… Automakers Toyota, Nissan, Honda, Mitsubishi and Suzuki [also] temporarily suspended production. Nissan may move one production line to the U.S. A total of 22 plants, including Sony, were shut in the area.[9]

As a result, the effects of a tsunami and related power disruption half the world away included a global economic impact totaling in the billions of dollars and lost economic productivity involving everything from consumer products to automobiles and companies in Japan, Vietnam and the United States, to name only a few. Given the trends of global trade and worldwide sourcing for everything from raw materials to consumer goods, industrial equipment, and even consulting and professional services, the scale of deleterious impacts from cascading failures in an interconnected world is significant and rising.

SOURCES OF THE GROWING RISK

Severity

Many risk analysts believe the most noteworthy trend of late has been the particular increase in probable severity of impacts from any significant disruption. The root cause of concern in this regard is the dramatic and mostly unconscious increase in the complexity of the interdependencies within our overall economy which mean that, because a disruption in a highly interconnected area like electrical power will have pronounced cascading effects across all manner of economic, transportation, telecommunications, and financial services industries, the severity of any disruption might be orders of magnitude worse than people would expect based on historical precedent. This was the case in the August 14, 2003, blackout in portions of the Northeast and Midwest United States and Ontario, Canada, causing an estimated economic loss of $6 billion in the United States alone.

Specifically, some of the main concerns in this regard include the personal and private sector costs of disruptions through lost productivity or damage to homes and workplaces, as well as the social impact of potential widespread death and destruction such as when a severe heat wave that hit France in 2003 resulted in some 14,800 deaths. At the same time, one must also take account of potential national and homeland security impacts stemming from the loss of power to critical command and control centers that would negatively impact the coordination of response efforts, potentially including even our nation's defensive forces.

Likelihood

The likelihood of the national power grid being impacted by adverse events is also on the rise due to myriad significant threats and hazards. In fact, according to the Department of Energy, of the five massive U.S. blackouts over the past 40 years, three of them occurred in the past nine years while the average outage from 1996-2000 affected

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[9] Kimberly Amadeo, "Impact of Japan's Earthquake on the Economy", About.com, May 16, 2012.

409,854 people, a 15% increase over the previous five-year period.[10] This is in large part because today's threats can stem from physical decay of the existing decades-old infrastructure as well as exposure of more and more of the system to the impacts of a growing population that is increasing per-person power consumption while moving both to crowded cities or spreading further and further into areas that were once scarcely inhabited.

Hazards also come from changing weather patterns that include major storms and more days and even weeks or months of extreme temperatures. As can be plainly seen from the challenges of combating droughts and the buckling of the pavement of American highways during the summer of 2012, for example, the manifestation of extreme hot or cold weather can push infrastructure beyond its design limitations, which in turn creates additional unforeseen cascading effects. While the impact to various physical linkages, couplings, substations, and other equipment of the power grid may be less visible than buckling highways, the results of the extreme temperatures on the built environment of the electrical grid are no less pronounced, including equipment failure, high-stress of the system, and shorter maintenance and replacement intervals for critical components.

Another important potential risk facing the electrical grid is that of malicious actors, be they terrorists like al Qaeda or Hezbollah, the military of other nations competing economically or otherwise with the U.S., or even lone-wolf anarchists or disgruntled employees. While attacks like these may seem unlikely, their intent and potential impacts mean they must be considered in terms of protecting the power grid, especially in light of the well-publicized potential cyber vulnerabilities of key segments of our existing electrical grid infrastructure.

SOME GOOD NEWS

The good news regarding the ability of the electrical system to absorb and recover from impacts is that for a variety of routine disruptions such as thunderstorms, minor substation failures, and the like our numerous economic and regulatory imperatives drive fairly resilient operations for much of the electrical power industry. In fact, the entire system is designed to meet a "3 nines" reliability standard, which translates to being 99.97% reliable.[11] This overall systemic resilience has evolved over time because industry participants have economic incentives to keep the system operating due to the regulations governing their operating agreements. For example, even if a local generation or transmission disruption occurs most power companies still have to provide power even if it means buying electricity at current market rates – even though those rates can spike precipitously during those same adverse events.

As a result, stable performance is an economic imperative because failure to keep the system operating can cost a tremendous amount of revenue to a firm. Power companies also have inherent incentives to implement process and structural solutions that minimize downtime following an adverse event, for in addition to regulatory concerns downtime means electricity is not being used and thus further lost revenues.

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[10] *The Smart Grid: An Introduction*, Department of Energy, Washington, DC, December 2008.

[11] The Galvin Electricity Initiative, "The Electric Power System is Unreliable."

The power companies fall under federal and state regulatory oversight for the operation of generating facilities and transmission systems, and the rates that local utilities are allowed to charge is generally regulated by state agencies.[12] This bifurcation of locally set rates but federally and state-mandated performance measures can cause tensions with regard to long term investments because the regulatory oversight prevents free market investments that can be recouped under normal financial operations such as freely-floating prices.

Nonetheless, the interplay between regulators and industry works in terms of meeting the routine decisions about investments that need to be addressed, and as a result of these drivers the electricity segment has proven generally highly resilient under most scenarios because its primary components can withstand massive localized degradation without necessarily impacting the rest of the system.

BUT SHARED RISKS REMAIN

Nonetheless, reliability is still a concern, and is intimately tied to resilience of the system. In fact, as noted by the Galvin Electricity Initiative regarding being 99.97% reliable, "while this sounds good in theory, in practice it translates to interruptions in the electricity supply that cost American consumers an estimated $150 billion per year."[13]

As another source reports, "The grid is designed to work at least 99.97 percent of the time, but just 0.03 percent still equals an average loss of 2.6 hours of power each year for customers across the U.S."[14] Furthermore, as CNN has reported, "Experts on the nation's electricity system point to a frighteningly steep increase in non-disaster related outages affecting at least 50,000 consumers… During the past two decades, such blackouts have increased 124 percent – up from 41 blackouts between 1991 and 1995, to 92 between 2001 and 2005, according to research at the University of Minnesota."[15]

But particularly pernicious is the shared nature of these risks. For example, too many industry players relying on the same few equipment suppliers for critical parts can result in an acute shortage after a large event. Potential transportation or supply chain interruptions further complicate the shared risks – whether for transporting raw materials to power plants or the mobility of power crews repairing various damaged infrastructure. It is from these kinds of unmanaged interdependencies resulting from today's complex world that the bad event can cascade into systemic collapse, as occurred following Hurricane Katrina in 2005. Addressing such issues through strategic resilience investments presents a host of inherently cross-sector and cross-segment challenges

> *America's electric system, "the supreme engineering achievement of the 20th century," is aging, inefficient, congested and incapable of meeting the future energy needs of the Information Economy without operational changes and substantial capital investment over the next several decades.*
>
> *- Grid 2030: A National Vision for Electricity's Second 100 Years, U.S. Department of Energy, 2003*

12 American Society of Civil Engineers, "Failure to Act," p.16.

13 The Galvin Electricity Initiative, *Id*.

14 Face the Facts USA Initiative, "A dramatic rise in power failures", August 19, 2012.

15 Thom Patterson, "U.S. electricity blackouts skyrocketing", *CNNTech*, October 15, 2010.

and requires concerted public-private partnership to identify and remediate the lack of flexibility and adaptability within certain key infrastructure nodes.

Even amid safeguards for routine risks, it remains an area of concern whether these drivers as currently understood by the industry partners are sufficient in today's world of non-linear and unpredictable risk. Prior historical experience, for example, is likely insufficient in terms of understanding the vulnerability of the system to targeted attacks – even if the current electrical system is reasonably secure against randomly generated failures occurring at random times and places it is still fragile in the sense that a targeted attack against a relative few key nodes could have significant disproportionate impact. This was the finding of Modeling Cascading Failures in the North American Power Grid, a 2006 study by researchers at Penn State University that concluded:

> The North American power grid has been proven both theoretically and empirically to be highly robust to random failures. However, this research highlights the possible damage done to the network by a more targeted attack upon the few transmission substations with high between-ness and high degree. Our results… suggest that even the loss of a single high-load and high-degree transmission substation reduces the efficiency of the power grid by 25%. This vulnerability at the transmission level deserves serious consideration by government and business officials so that cost effective counter measures can be developed.[16]

Unfortunately, the ill-defined roles and overlapping responsibilities for public, private and other parties mean that solutions to certain types of non-routine challenges fall into the gaps between segments and sectors. These include preparing for uncommon but highly consequential hazards, as well as addressing interdependencies that lie beyond anyone's specific remit but which, if left unaddressed, could lead to cascading failures across multiple critical infrastructure segments and sectors. Such areas of shared aggregate risk can be considered governance gaps in the sense that they occur where no specific entity has direct control over or responsibility to manage the shared and interconnected risks.

Significantly, these governance gaps are most prevalent regarding low probability, high consequence events. As a result, the electrical system tends to be resilient against high and even medium-likelihood events, but less prepared for the massive cascading effects that stem from the multi-faceted disruptions to workforce, supply chains, and electricity generation and delivery that would accompany certain low-likelihood but high consequence events such as massive earthquakes, nuclear or biological terrorism, or other catastrophic events. It is in addressing these types of events where the most significant of the governance gaps arise, for the private sector owners and operators of much of the nation's critical infrastructure, including the electrical grid, have less direct impetus to address these gaps than they do the more routine hazards.

Another significant gap is addressing so-called future risk, a notion that stems from the need to focus not only on linear historical patterns but also on changing trends, processes, and technologies that will affect interdependent critical infrastructure resiliency in unforeseen

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[16] R. Kinney, P. Crucitti, R. Albert, V. Latora, (2005), Modeling Cascading Failures in the North American Power Grid, *Physics of Condensed Matter*, 46, 101-107.

ways. This is crucial to address because long-term planning assumptions tend to be built around historical patterns, but these patterns may be very, very wrong as the evolving picture of future risk means the frequency or magnitude of outages changes sharply over time.

This type of risk is emerging as a major concern given that changing weather patterns are resulting in more and more days at the extreme ends of the temperature range and some of the underlying systems were not designed to operate under such conditions for prolonged periods. Another example of this type of future risk is the role of ubiquitous telecommunications in all of our lives and most or all business and government functions. With the extreme reliance upon electricity as a critical enabler of telecommunications the significance of any disruption increases, as evidenced by how firms relying on voice over internet protocol (VOIP) phones cannot use them if their access to the internet is down, or if the internet itself has disrupted service.

In dealing with such changes by looking to the future needs for a more resilient electrical power grid there are two key trends to consider: running at peak capacity, and costs today for savings and benefits tomorrow.

CAPACITY CONCERNS

As described by National Geographic, "In Canada and the U.S. the grid carries a million megawatts across tens of millions of miles of wire. It has been called the world's biggest machine."[17] And yet there is a significant and inexorable trend of operating at or near absolute peak capacity within the system as demand continues to grow more quickly than supply. This inherently raises the risk of more and larger blackouts, for each fault that occurs at or near the peak load by definition occurs when there is less slack in the system, and there is a decreasing amount of slack overall. Specifically, each system operates under governance regimes that require excess capacity of 10-15% greater than the anticipated peak demand.

The system tends to be less prepared for the massive cascading effects that stem from the multi-faceted disruptions to workforce, supply chains, and electricity generation and delivery that would accompany certain low-likelihood but high consequence events.

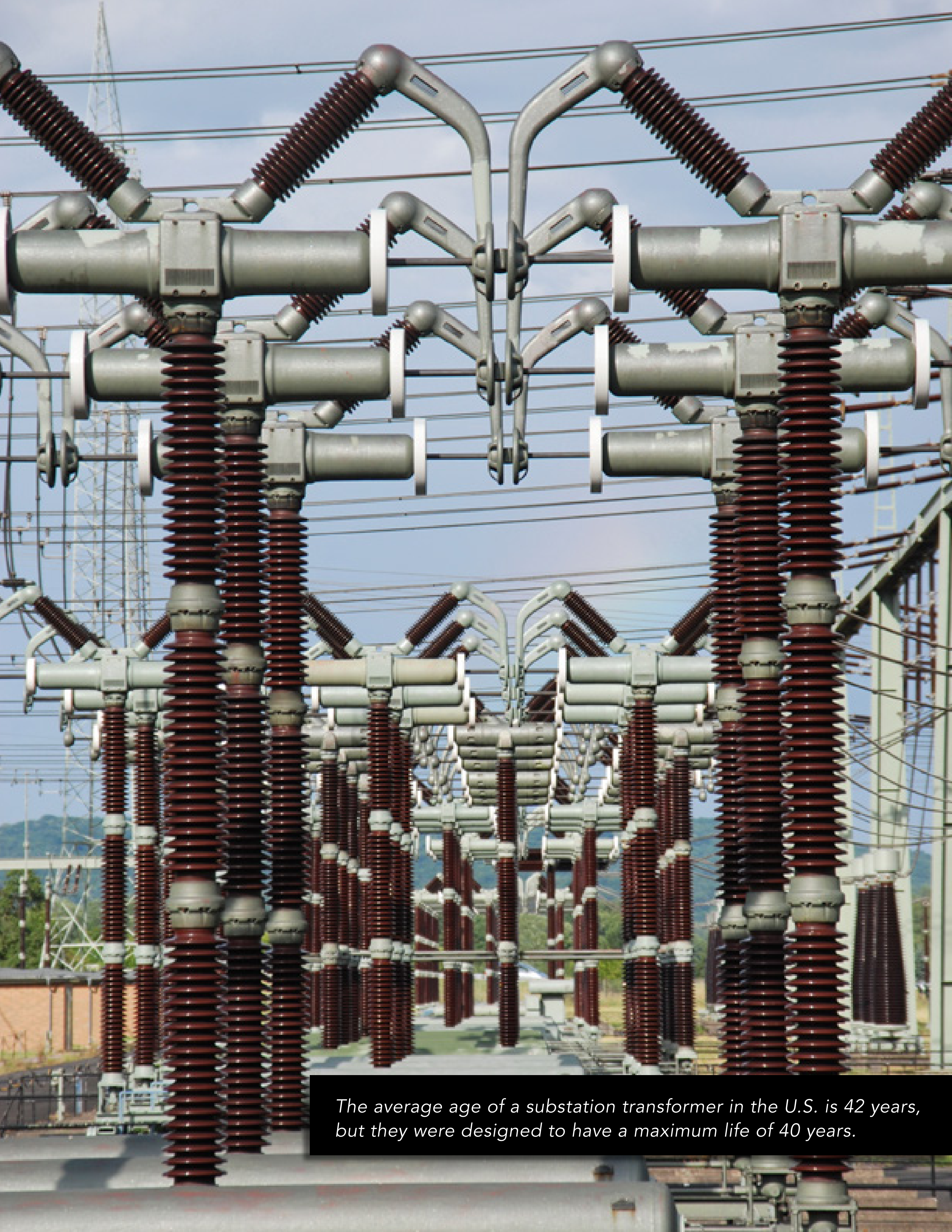
Despite this, in some areas there is already a failure to meet those standards, and recent analysis suggests that Texas, in particular, will have a reserve margin of only 9.8% in 2014, 6.9% in 2015, and will exceed its capacity reserves by 2022.[18] Resolving the mismatch between peak demand and available capacity will require either additional power generation in terms of new or expanded power plants or better management of current usage levels by spreading out demand across non-peak hours – a main driver behind the ideas of the smart grid.

COSTS TODAY, BENEFITS TOMORROW

In terms of building in greater resilience through a smarter grid, there are significant costs, but also important gains, associated with a transition to many of these new technologies. The costs include the initial build-out of one or two-way communications devices

17 Joel Achenbach, "The 21st Century Grid: Can we fix the infrastructure that powers our lives?", *National Geographic*, July 2010.

18 " Texas power supply outlook worsens, grid says", Reuters, May 22, 2012.



The average age of a substation transformer in the U.S. is 42 years, but they were designed to have a maximum life of 40 years.

within the existing footprint of the current electricity consumers. For example, while it can be shown that the labor savings enabled by remotely reading power meters will save tremendously on costs over time, physically replacing and connecting the new meters still involves a significant up-front cost, for it requires upgrading the current analog meters, which cost about $40 each, with newer digital and communications-enabled smart meters costing as much as $200. When this is multiplied across the many millions of household and business users the costs mount up quickly. Similarly, upgrading the readers will also require upgraded information systems to handle all the newly available data and to be able to remotely control various key parts of the system. Furthermore, the shift to a smart grid involves more than just infrastructure upgrades – it also means a need for large-scale retraining of the workforce to operate in a smart-device enabled environment.

On the other hand, smart grid benefits include not only gains from better managing daily use and reducing load on the system during peak capacity hours, but also determining when and where throughout the system a problem has occurred. This is because with real or near-real time monitoring of the system the ability to modulate the levels of electricity being generated and delivered will be much more precise. Furthermore, the smart grid will allow operators the ability to isolate discrete sub-sections of the grid which facilitates bringing back online those adjacent but unaffected areas that currently now get caught up in the less precise neighborhood or local area power shut-offs.

Experts note a frighteningly steep increase in nondisaster-related outages affecting at least 50,000 customers.

Another form of tangible savings comes from cost avoidance by circumventing the need to build additional infrastructure to service peak capacity that is used only on relatively rare occasions. This can be achieved by optimizing the management of electricity demand during peak periods, specifically by automatically communicating with industrial and household consumers so they can make more informed choices about their consumption relative to total demand on the system or even allowing power companies to control from afar such relatively minor aspects as a household's air conditioning or other major appliances. While this may seem trivial, the Department of Energy has noted, "10% of all generation assets and 25% of distribution infrastructure are required less than 400 hours per year, roughly 5% of the time. While smart grid approaches won't completely displace the need to build new infrastructure, they will enable new, more persistent forms of demand response that will succeed in deferring or avoiding some of it." These considerable savings therefore come not from decreasing the amount of total power created or by reducing the amount used, but rather from better managing the specific times that the amounts required are used.

As a nation, we will need to find better ways to manage these areas of shared responsibility stemming from current and future evolutions of the aggregate and shared risk picture. This requires finding solutions that blend broader risk management needs for a more resilient electrical grid with the private sector's ability to invest in ways that meet challenges effectively and efficiently. It also requires an open dialogue about the full costs and potential benefits of a more interactive and modernized smart grid that allows consumers to help by reducing demand during peak periods and provides deeper insights into the otherwise opaque real-world operating conditions of the grid itself. Ultimately these costs will be borne by the consumer, and yet individual consumers have a hard time recognizing the incrementally more resilient aspects of the system, such as the smarter grid that tracks faults and problems more accurately can enable better overall system management through increased situational awareness, enabling early and better intervention and reducing incidents.

REQUIREMENTS FOR A MORE RESILIENT SYSTEM

Despite our increasing dependence upon our electric grid, for all too many of us it is essentially invisible, and as a result we take a properly functioning and secure grid for granted. This is true despite the fact that on any given day, some 500,000 Americans experience a power outage.[19]

Fortunately, most of these outages are brief and their occurrence is spread across the entire population, as opposed to being a chronic problem in any specific area. Indeed, with the possible exception of California during the late 1990s, multiple generations of Americans have never really had to contemplate life with prolonged periods of routine disruption and widespread service outages.

Nonetheless, the potential economic impacts of disruptions are already significant. According to the Galvin Electricity Initiative, annual interruptions to the electrical supply cost the nation an estimated $150 billion.

Annual U.S. Power Disruption Costs by Industry[20]

Industry	*Average Cost of 1-Hour Interruption*
Cellular communications	*$41,000*
Telephone ticket sales	*$72,000*
Airline reservation system	*$90,000*
Semiconductor manufacturer	*$2,000,000*
Credit card operation	*$2,580,000*

At the same time, the steady and reliable flow of proper voltage and quantity of electricity is increasingly important as productivity in our professional and personal lives becomes ever more dependent upon sensitive computer chips and other devices with minimal tolerance for disruptions and power fluctuations. For example, the amount of the total electrical load used by devices with computer chip technologies was approximately 40% in 2011, and will be up to 60% by 2015.[21]

19 Thom Patterson, "U.S. electricity blackouts skyrocketing", CNNTech, October 15, 2010.

20 "The Electric Power System is Unreliable", Galvin Electricity Initiative.

21 The Smart Grid: An Introduction, U.S. Department of Energy, Washington, DC, December 2008.

Furthermore, systemic risks to the nation's overtaxed electric grid continue to grow in size, scale and complexity. When one accounts for the central economic role but also the many various threats, hazards and concerns associated with protecting this sprawling, decentralized, and essential system it is clear that collective action to ensure the longevity and resilience of the electrical grid is in our best interests.

What should that action look like, what forms should it take? Simply put, the two main aspects in assessing risk can be defined as the sum of the likelihood and severity of an adverse event. It therefore follows that the best means of reducing risk is to take steps that either reduce the likelihood of an event or that reduce the severity should an event occur. This corresponds to the following practical recommendations, each of which individually and in concert contribute to a more resilient electrical power system.

REDUCING THE LIKELIHOOD OF DISRUPTIONS

Among the grid's three primary components (i.e., generation, transmission, and distribution), it is the local distribution segment where most disruptions typically occur. This is in part because federal regulatory requirements ensure that the generation capacity includes not only enough to meet peak demand but also a 10-15% reserve, which is generally sufficient to avoid disruption within generation, and the long haul transmission lines are also strongly regulated and generally well maintained. It is the more localized distribution systems that tend to cause the problems. This can include downed power lines, transformer malfunctions, and underground equipment failures.[22]

The primary set of preventive measures includes two main categories, routine repairs and use of "tripwires".

Effects of Electricity Interruption on U.S. GDP and Jobs 2012-2020[23]

	Average Annual Impacts	*Cumulative Losses*
Gross Domestic Product	*-$55B*	*-$496B*
Jobs	*-$461,000*	*NA*
Business Sales	*-$94B*	*-$847B*
Disposable Personal Income	*-$73B*	*-$656B*

Note: Losses in business sales and GDP reflect impacts in a given year against total national business sales and GDP in that year. These measures do not indicate declines from 2010 levels.
Sources: EDR Group and LIFT model, University of Maryland, INFORUM Group, 2012.

Fully funding routine maintenance and timely repairs and replacements of parts across the system. Preventive maintenance and clearing of debris and growing trees are critical aspects of risk management for nearly all infrastructure and electrical power grids are no exception. However, in practice the power companies face a number of challenges from federal, state and local rules and regulations. For example, while the need to ensure worn out parts are replaced quickly and that trees and other natural obstacles are kept clear of

[22] American Society of Civil Engineers, "Failure to Act," pgs. 32-34.

[23] *Ibid.*, p.9.

Resilience is the ability to avoid or absorb impacts while continuing or rapidly resuming operations at an acceptable level.

the power lines is well documented, the ability to conduct these and other reasonable preventive activities often is limited because of resource constraints and legal challenges based on right-of-way and potential environmental impacts. Sadly, these real-world obstacles can complicate or delay basic maintenance and upgrade activities and pave the way for massive infrastructure failures and cascading negative effects.

Nonetheless, such impediments must be addressed because routine investments in preventive measures can help minimize or avoid events and in turn save orders of magnitude of costs by preventing events from coming to pass. For example, the cost versus benefit of routine maintenance and clearing lines can be seen quite dramatically from the case of the 2003 Northeast Power blackout – North America's worst ever such event – which was initiated by high voltage lines brushing against overgrown tree limbs in Ohio and ended up affecting some 50 million people and causing losses in excess of $6 billion. Similar right-of-way disputes complicate the already arduous task of maintaining hundreds and hundreds of miles of infrastructures and impede routine maintenance across the system, causing delays and missed opportunities for cost-effective pre-event risk mitigation.

Building in systematic circuit-breaker tripwires that will temporarily shut down a portion of the system whenever a given safe operating range of temperature or some other

Electrical outages cost U.S. consumers and businesses over $119 billion annually.

defined variable is exceeded is another important means to reduce the likelihood of disruptions. While the grid does currently have circuit breakers at some substations there are also many fuses that, unlike circuit breakers, must be replaced in order to restore the flow of power. In a period of volatile environmental factors and changing usage patterns the lack of more easily reset circuit breakers is a major shortcoming because we need an approach that is more flexible.

For example, it may be necessary to isolate entire segments of the grid to prevent troubled areas from taking the rest of the regional grid with them when they falter. The ability to quickly restore functionality once the anomaly passes is also vital. This level of insight requires us to gain better knowledge of routine operations and deviations from typical usage patterns. Fortunately, we are headed in the right direction because these are precisely the objectives of many aspects of the smart grid. Real-time, two-way communication of specific usage data will enable many more detailed measurements of various operating conditions and enable the operators of the power grid to safely quarantine malfunctioning parts before their impacts can cascade across the rest of the system.

MINIMIZING IMPACTS – FIVE STRATEGIES

Regardless of how many preventive steps are taken or how well they are implemented, the reality of operating such a complex and broad-based system in a dynamic technological age means that inevitably there will be disruptions and outages, be the cause human error, technological failure, criminal or terrorist act, or simply an act of nature. Therefore the second critical aspect of reducing overall risk and promoting resilience involves a focus on five main areas: redundancy, safety stocks of spare parts, substitute systems, the ability to manage or shift demand, and ensuring that alternative production facilities are available in unaffected sectors of the grid.

REDUNDANT CAPABILITIES

The first approach, redundancy, is often the most expensive and is only used sparingly because the investment in and upkeep of excess capacity runs counter to the private sector's chronic operational cost cutting imperative to more efficiently manage the balance between demand and supply of everything from raw inputs to spare parts and power generation, transmission and delivery. Nonetheless, ensuring a certain excess capacity of redundant capability is appropriate for a few select items where repair is exceedingly difficult and/or a failure would have such a large impact as to render it unacceptable. Indeed, in terms of generation capacity the system has a significant amount of required redundancy in that the operators are generally required to maintain a capacity of 115% of their peak demand requirements, providing a 15% cushion, albeit at an extraordinary cost relative to the more routinely used base load generation.

ROBUST SUPPLIES OF STANDARDIZED, INTERCHANGEABLE SPARE PARTS

A related issue is the movement towards sufficient safety stocks of spare parts. This includes interchangeable parts and standardized designs that can be replaced in whole or as separate modules serving discrete purposes, and also standardizing the interfaces of everything from physical gaskets and valves to interoperable control systems and computers using seamlessly integrated enterprise software systems. The efficiency gains from standardized parts that are interchangeable come from having many fewer parts in inventory and also being able to quickly replace part or all of a damaged system with equivalent "off-the-shelf" as opposed to specially designed parts. This approach applies to many modern industries but was not a feature of the original designs of the decentralized power grid infrastructure, which means there is a great variance among the sizes, power requirements, weight, and other characteristics of many critical generation, transmission and distribution parts. More uniformity would enable cost-effective solutions because instead of having in place fully redundant capacities that go unused day to day this approach relies on standardizing select equipment and infrastructure and the storage of some interchangeable spare parts. An added benefit of this approach would enable stockpiles of spares to be shared across regions, and across firms, to more broadly spread out the cost of buying and storing them.

SUBSTITUTE SYSTEMS

The third significant approach to resilience is to identify substitute systems that can be used in the event of a disruption affecting the primary system. For a typical user this generally means ensuring access to a proper sized generator and sufficient amounts of fuel to operate it to run at least your most critical systems for a prolonged period without having to rely upon the grid. Another example of substitute systems on a larger scale would be finding ways to physically connect the flow of power among and across the four essentially separate regional power grids servicing North America. For example, the proposed Tres Amigas project in eastern New Mexico would share generated power across a large loop of multi-gigawatt-capacity superconducting cable for the Eastern, Western and Texas interconnections to allow the excess capacity within one system to flow to the affected system.

IMPLEMENTING PEAK DEMAND MANAGEMENT TACTICS

Fourth, shifting the timing of household electricity use is an effective way to reduce the demands upon an impacted system. For example, automatic messages sent to many thousands of users during critical peak periods could enable them to voluntarily reduce their usage by delaying the use of laundry machines or dishwashers and raising or lowering the thermostat a degree or two. Dynamic pricing models offer incentives for non-peak energy use. While the impact to each user would be minimal, the overall aggregate demand reduction could enable the entire system to meet total need without requiring additional generation capacity. In severely impacted areas such techniques as scheduled rolling black-outs could be used. Because such decisions will hold drastic impacts for consumers and other stakeholders, processes for involving them in deliberative processes will be necessary.

INCORPORATING STRATEGIC PRIORITIES FOR DIVERSIFYING CRITICAL CAPABILITIES

Finally, significant resilience gains could be realized by managing industrial demand by shifting to alternative industrial production facilities located in unaffected regions of the grid. This would require a level of redundant production capacity that is not consonant with current standards for lean manufacturing and just-in-time delivery. Should an event as large and severe as Hurricanes Katrina and Sandy happen again, such an approach could reduce overall demand to a level that the impacted system, though impaired, can meet.

In practice this would require implementing tax incentives and other cost-saving measures that would help ensure that energy intensive and/or critical goods industries have geographically disparate production facilities.

While strategically desirable, such moves would not only carry major associated costs, but with substantial numbers of jobs connected to these facilities, their impacts on communities that include tax bases, schools and even voting patterns could be substantial. This would create further social and political concerns. Ideally, this approach could be used on a purely voluntary and organized basis that includes thorough cost-benefit analyses and development of a true public-private partnership. Although, inherent complications of addressing national priorities through both local politics and state regulatory infrastructures must be expected.

In a period of volatile environmental factors, the lack of more easily reset circuit breakers is a major shortcoming.

The above examples of specific tools and means of achieving greater resilience could significantly improve our national power grid and the economic prospects dependent upon it. However, in the real world there are important trade-offs that must be made that present challenges for regulators. For example, keeping consumer costs as low as possible versus relaxing the controls on the price of electricity to allow for higher returns that can fund modernization and spare capacity, while maintaining pricing that does not require consumers in one jurisdiction to subsidize those in another. The use of price ceilings and caps on what utilities can charge is a double-edged sword in this regard because it both protects today's consumers from volatile and increasing prices and also stifles the free market's ability to fully invest in decades-long infrastructure improvement projects because costs may not be able to be recouped and therefore returns are uncertain.

While there are no easy answers or painless trade-offs, these are significant public policy issues that need to be addressed in advance of an adverse event because, importantly, the cost of taking these measures pre-event is significantly less than suffering a major systemic collapse. In this manner, additional resilience is like a form of insurance because it involves a small, consistent payment that defrays the potential impacts of an adverse event. And, as with insurance, if you wait to invest until the day you really need the protection you have waited too long.

Addressing the 16 percent of all generated electricity lost during transmission would save tens of billions of dollars annually.

KEY INVESTMENT AREAS AND NEXT STEPS

It has been widely observed across many aspects of life that, "knowledge is power," and this certainly holds true in the case of knowing what is happening, and why, across the many pieces that comprise the electrical power grid. Specifically, because electricity from the grid cannot be stored and must instead be continuously generated and transmitted and then instantly consumed, the power of knowing in real-time the precise demand, actual supply flows, and any anomalous energy losses throughout the system is even more important than in many other arenas.

Indeed, many of the most important of the ongoing grid modernization and infrastructure improvements currently underway are aimed at this very issue – the development of a so-called "smart grid" that can (among other facets) better track power usage, measure it against traditional usage patterns, and identify anomalies.

In particular, the increasing application of advanced analysis tools coupled with wireless communications embedded within many devices and enabling distributed real-time monitoring is increasing efficiency by improving our ability to find and fix problems earlier than was previously possible. This includes better targeting of recovery efforts when anomalies do occur.

This ability to conduct real-time monitoring of energy generation, transmission and delivery, as well as other whole-system performance indicators, is especially relevant to the issue of effective energy management. By avoiding wasteful systemic failures the time required to intervene if and as warranted is reduced.

In other words, without the right monitoring devices in place, we won't know there is a problem until it is too late to either avert or at least minimize an adverse event. This lack of situational awareness has effectively increased the likelihood of facing preventable disruptions, such as energy being wasted by flowing unregulated out of the system at a broken substation linkage, or perhaps overloading and eventually crippling a critical node or power line.

As it turns out, however, knowledge may translate to power, but not all knowledge is created equal, and some means of acquiring it are not as efficient as others. For instance, in the rush to develop and deploy residential-use "smart readers" over the past few years, there was a lack of focus on developing specific industry standards and interoperable systems that would have saved money in the long run by being standardized, interoperable and/or interchangeable. Unfortunately, the rollout of nonstandardized technology solutions reduced the ability to achieve wide-scale interoperability, ultimately costing users money as potential savings are either forfeited or achieved only by retrofitting or replacing these early systems.

In the final analysis, however, the failure to develop better standards and more interoperable systems before moving ahead with widespread deployment should not detract from the clear case for continuing to move towards a knowledge-centric power grid. Rather, the case for moving ahead with the smart grid and related improvements is a classic case of costs versus benefits. Although the true magnitude of both the costs and the benefits are hard to fully predict and are playing out on such a massive scale that even small deviations can matter significantly, some of the relevant considerations include:

- Plans to modernize our vast power grid are estimated to cost $1.5 trillion over 20 years, or some $75 billion per year for the next 2 decades.[24]
- Each year American households and businesses lose an estimated $20 billion per year in direct losses of electric power, and up to $150 billion in total losses.[25]
- The costs of such losses will surely continue to rise in an era of increasing demand for electricity and as more people work outside of the office and consumers begin to plug in not only their phones and laptops but also their cars.
- Even without the smart grid there would be significant investments required to keep the current antiquated system operating, including expansion to meet growing demand.
- Without the smart grid we can't develop insights and persistent monitoring of the system to develop an accurate understanding of ongoing usage patterns and evolving needs.
- Though hard to quantify, there certainly will be efficiency, safety and security benefits of much deeper knowledge about real-time events in and around the power grid, as well as environmental and other benefits from modernization.

Devices with computer chips will use 60 percent of the total U.S. electrical load by 2015.

[24] "A dramatic rise in power failures", Face the Facts USA, August 19, 2012.

[25] *The Smart Grid: An Introduction*, U.S. Department of Energy, Washington, DC, December 2008.

- *A stronger power grid will be more reliable, significantly reducing the immense cost of power out ages for American consumers and businesses. The 2003 blackout in the Northeast U.S. and Canada caused upwards of $6 billion in economic losses.*
- *A state-of-the-art high-capacity transmission line can carry as much electricity as six standard lines, at 1/3rd the cost, using 25 percent less land, and with 1/10th the line losses.*
- *Smart grid enabled energy management systems have proven in pilot projects to be able to reduce electricity usage by 10–15 percent, and up to 43 percent of critical peak loads.*

- Derived from multiple sources as compiled by the Energy Future Coalition's "Transmission Smart Grid Fact Sheet", February 20, 2009

America's incredible but also increasingly outdated electrical grid is in need of significant investment. Even the U.S. Department of Energy has assessed the grid to be, "aging, inefficient, and congested, and incapable of meeting the future energy needs of the Information Economy without operational changes and substantial capital investment over the next several decades."[26] And yet an American Society of Civil Engineers study found present levels of annual funding leave a significant gap, and that without increased investments, the failure to invest adequately and strategically, "will result in a cost to businesses and households, starting at $17 billion in 2012 and growing annually to $23 billion by 2020 and $44 billion by 2040. The cumulative costs of power outages approach...$1 trillion by 2040."[27] Such numbers are intimidating, but so is the fact that we need perhaps as much as $1.5 trillion of investment over the next 20 years if we fully invest in a national smart grid.[28]

Aging assets in today's grid further increase the urgency. "In the United States, the average power generating station was built in the 1960s using technology that is even older. The average age of a substation transformer is 42 years, but the transformers today were designed to have a maximum life of 40 years."[29] Furthermore, "In 2011, Americans experienced a combined 104,406 hours of power outages across the country (4,435 incidents), up 67 percent in just three years."[30] More to the point, some 20 percent of the sustained outages (defined as lasting more than one minute) were caused by failing electrical equipment.[31]

Fortunately, according to some estimates fully implementing the smart grid could save $46 billion to $117 billion over 20 years in the avoided construction of new power plants and power lines, because a smart grid would use electricity so much more efficiently that we would need less new generation capacity.[32]

26 "Grid 2030: A National Vision for Electricity's Second 100 Years", U.S. Department of Energy Office of Electric Transmission and Distribution, July 2003.

27 American Society of Civil Engineers, "Failure to Act," p.40.

28 "U.S. electricity blackouts skyrocketing", Thom Patterson, CNN, October 15, 2010 7:26 p.m. EDT.

29 "What the Smart Grid Means to Americans", U.S. Department of Energy, accessed November 2012.

30 "A dramatic rise in power failures", Id.

31 *Ibid.*

32 "What the Smart Grid Means to Americans", Id.

Additionally, assessments of costs versus benefits also must include not just routine operations and equipment upgrade costs but also the magnitude of potential future failures. As we continue to develop our ever more interconnected and increasingly electricity-dependent society, the potential costs of even a single incident continue to rise. For example, many Americans remember when overgrown trees on power lines triggered the Northeast blackout in August 2003, an incident that then cascaded across an overloaded regional grid. As CNN has reported, "An estimated 50 million people lost power in Canada and eight northeastern states. Smart grid technology, experts say, would have immediately detected the potential crisis, diverted power and likely saved $6 billion in estimated business losses."[33]

THE BENEFITS OF INVESTING IN RESILIENCE

Embedding resilience within the electrical grid is about three main categories of investment: 1) managing and meeting overall demand to help avoid an adverse event; 2) expanding alternatives or substitute systems before and after an event; and 3) enabling rapid reconstitution if and when a disruption does occur. Fortunately, the implementation of each type of solution often carries over benefits across to one or both of the other categories, for the tools and the knowledge that can help avoid an event can also be useful in response and recovery efforts. A few specific examples of improvements in terms of these three categories are detailed below.

Managing and Meeting Overall Demand

One clear need within the mission to manage demand is to improve the efficiency of the performance in terms of the generation and delivery of the energy we already create. Indeed, as one industry player has noted, "Around two-thirds of primary energy is lost, mainly due to power conversion, and up to 16% of the electricity generated never reaches users – it is lost by the networks, like water leaking from a pipe. The U.S. Energy Information Administration calculated that electricity lost in transmission and distribution cost the economy $20 billion in 2005."[34] Investing in more modern means of generation to improve efficiency at that point in the process is certainly required, but even addressing the 16% lost during transmission represents a significant potential savings. Solutions to these two issues require the use of more modern facilities and also upgraded and more technologically advanced equipment that can measure power flows across the system quickly and at a more granular level.

Another key aspect of managing demand is to incorporate smart grid solutions that reduce the load required during peak periods. The most often discussed step in this direction is the use of smart meters tied to two-way communications between producers and consumers. This type of system, if properly configured with interoperable standards to ensure complete interoperability, would allow consumers to be notified when rates are higher because of rising demand so they can make an informed decision about their current demand or even allowing the power companies to directly modulate a customer's periodic demand

[33] "U.S. electricity blackouts skyrocketing", Id.

[34] "Challenges of electrical grids", Alstom, accessed November 2012

based on pre-negotiated terms. This has the potential for substantial savings in terms of the need for new plants that are only used during peak periods.

The Department of Energy estimates, "Hooking up $600 million worth of new smart appliances to the smart grid could provide as much reserve electric power for the grid as $6 billion worth of new power plants."[35]

A third and equally significant aspect of managing demand is to devise better and more efficient means of storing energy for later use. While the primary focus in this regard has been to develop larger and more powerful batteries, several more conventional and mechanical methods also are in use and could be expanded. These include, for example, using surplus power during high production times (i.e., during daylight for solar powered systems or during strong winds for wind mills, etc.) to pump water uphill to fill a large water reservoir that can be released later to power the generators in a dam, or pumping air into an underground cavern and compressing it to more than a thousand pounds per square inch, then releasing it during the next day to spin a turbine. Expanded use of such storage techniques could help to even out the cycles of power generation and usage, thus reducing the peak-load problem and the need to invest in costly peak-load-only generation capabilities.

It is becoming increasingly difficult to site new conventional overhead transmission lines, particularly in urban and suburban areas experiencing the greatest load growth. Resolving this siting dilemma, by a) deploying power electronic solutions that allow more power flow through existing transmission assets and b) developing low impact grid solutions that are respectful of land use concerns, is crucial to meeting the nation's electricity needs.

- Grid 2030: A National Vision for Electricity's Second 100 Years, U.S. Department of Energy, July 2003

Expanding Alternative Sources

Given the desire to ensure the flow of electricity regardless of what challenges or changes may occur, there is a need to ensure the availability of supplemental electrical power for routine use as well as to be available if the main grid should be impaired. Perhaps the most important means of increasing additional sources of energy supply across each of the nation's three power grid segments is the rather obvious strategy to connect them together, such that if one were affected it could draw power from the others.

An effort is currently underway to achieve this idea, although funding is uncertain and the timeline is not yet finalized. Located in Clovis, New Mexico, where the three grids come closest to each other, the Tres Amigas Superstation would connect the grids with a loop of five-gigawatt-capacity superconducting cable.[36] According to the proposed builder of the nearly $2 billion effort, Tres Amigas, LLC, "First announced in 2009, the Tres Amigas project includes building a hub across 22 square miles of rangeland in eastern New Mexico. It would serve as the meeting point for interconnections that serve the eastern and western halves of the U.S. and a separate grid that supplies Texas."[37] Clearly having the ability to

[35] "Challenges of electrical grids", Alstom, accessed November 2012.

[36] Joel Achenbach, *Id.*

[37] "Overview", Tres Amigas LLC, accessed at http://www.tresamigasllc.com.

share generated power across the artificial boundaries separating the three main U.S. grids would be a significant improvement in terms of overall resilience.

Another important aspect of developing alternative sources is to use technology to centrally control the generation of electricity from multiple alternative sources, or the creation of so-called "virtual power plants" by using automated control systems able to aggregate and economically optimize the dispatch of distributed generation resources.[38] This approach also helps avoid massive infrastructure investments but also enables efficient and effective integration of variable power sources into the grid on a scale that would be relevant to the overall challenge of generating, transmitting and delivering enough electricity to meet all of our needs.

Enabling Rapid Reconstitution

Many important aspects of enabling rapid reconstitution of the electrical power system are included in the solutions addressed above, including implementing smart meters and related situational awareness technologies. Such technologies have the ability to help pinpoint anomalies more quickly as well as to better understand where and how a disruption has occurred, which is the first step in fixing the problem. Similarly, modernizing generation and transmission infrastructure and the development of the Tres Amigas Superstation and virtual power plants are also relevant to enabling rapid reconstitution, for each of these actions would increase the amount of available electrical power that could be drawn upon following an adverse event.

An additional investment area with specific appeal in terms of rapidly reconstituting a disrupted or damaged system is the broader use of interchangeable parts throughout the system so as to enable even small stockpiles of spare parts to be able to cover a larger number of critical pieces of equipment. This is essential because the reality of today's grid is that it sprang up somewhat organically and without centralized planning, resulting in hand-made or single-purpose items for which replacement parts are not immediately available. This means that following an event some critical piece may have be made to order and then delivered as a whole, often from overseas and, in the case of large power transformers that can weigh up to 340 tons, using specially designed equipment.

Another potential solution is the use of temporary local area generators that could power large blocks or segments of a city. These so-called "micro-grids" are in essence a cross between the largest of today's truck-mounted mobile generators and a miniature power plant. They could be prepared for use following events, or even pre-positioned and connected for use in advance of an event, most likely serving certain critical nodes such as the New York City financial district, the federal buildings in Washington, DC, and airports or other significant areas.

A final area for consideration is to address systemic interdependencies that lie beyond the grid itself, such as examining regional preparedness for critical infrastructure disruptions that involve telecommunications, transportation, and water networks. Because each of these infrastructure systems operate independently but also are highly interdependent, any assessment of the ability to ensure the repair of impaired or inoperable

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38 "Siemens Microgrid Solutions", accessed November 2012.

electrical power infrastructure must account for the inherent need, for example, to have working communications, passable roads, and available water for safety and firefighting.

CONCLUSION: INVESTMENTS MUST BE SMARTER, TOO

The U.S. power grid of today is fairly effective at producing abundant and cheap energy, and is reasonably reliable relative to routine events and disruptions. However, as noted by National Geographic, "our demands are increasing and changing… we need more, and we want it at different times and from different sources. There are bills to pay with all those adjustments."[39] The large scale of these investments means that the decisions must stand the test of time, with implications for household and business consumers likely to last for decades.[40] Several of the main issues in considering smart grid investments can be summarized as follows:

- Smart grid estimated cost: $1.5 trillion
- Smart meters: 26 utilities in 15 states have installed 16 million
- Number of people on average affected daily by U.S. power outages: At least 500,000
- Yearly cost of U.S. outages: At least $119 billion
- Number of U.S. electricity customers: 143,275,635
- Number of U.S. power utilities: More than 3,000
- Total U.S. high-voltage lines: 157,000 miles
- Cost of new high-voltage lines: $2 million/mile when installed underground for greater resiliency[41]

Significantly, in the decision about the proper path forward we must account for the reality that the current risks facing the nation's electrical power grid are increasing due to many reasons, with the following among the most important:

1. We have a predominantly outdated and decades-old core set of electrical grid infrastructure comprised of several key elements that have been often patched but rarely or never redesigned and modernized, resulting of lost productivity from failures and outages due to practical issues like fatigue, parts failure, and misalignment of the system with how we consume power today.

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[39] Joel Achenbach, Id.

[40] *Ibid.*

[41] Thom Patterson, "U.S. electricity blackouts skyrocketing", CNNTech, October 15, 2010.

2. We face ever-increasing demand from growth in both population and in per-person power consumption.
3. We are witnessing a significant uptick in risk across the entire system due to threats and hazards that include natural disasters and shifting weather patterns, terrorist and other asymmetric attacks from state and non-state actors, increasing cyber vulnerabilities, and even traditional threats like disgruntled workers or insider malfeasance.

The obvious conclusion and simple truth about ensuring the resilience and long-term viability of our national power grid is that we have a clear need for greater information in order to better monitor and manage disruptions across the system. Implementation of the smart grid approach would go a long way towards providing the necessary information that could enable us to better protect assured access to this critical aspect of our everyday lives. This is because the smart grid would have three primary impacts:

1. Reducing peak load demand by informing consumers of variable costs to have them reduce their usage during times of peak usage or possibly even having the supply-side utility operators directly control certain demand-side power requirements;
2. Integrating two-way electrical power flow to enable renewable and other distributed generation sources to feed into the grid; and
3. Increasing real-time operator situational awareness of what is happening to and across the power grid, enabling both better routine operations as well as faster response and recovery should an incident occur.

Unfortunately, the nature of the shared dependence on the electrical power grid without shared responsibility for keeping it operating regardless of what adverse events may take place results in real-world challenges for developing appropriate resilience across the system. Therefore what is called for is a significant national deliberation on the merits of the required systemic improvements, and the development of a workable roadmap to get us there. Otherwise, we may well wake up one day and find ourselves in a world without instant, ubiquitous and affordable electrical power running all those street lights, communications towers, hospital equipment, and the million other necessities and conveniences upon which we have come to rely.

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