The Case for Smart Grid

Funding a new infrastructure in an age of uncertainty.

By Massoud Amin

We are witnessing today the birth of a new mega-infrastructure. It will emerge from the convergence of energy with telecommunications, transportation, Internet, and electronic commerce.

Starting with the electric grid, which underpins all of these interdependent systems, new ways are being sought to improve network efficiency and eliminate congestion problems without seriously diminishing reliability and security. But with these efforts come uncertainty – plus a general disruption to industry and commerce that may well prove greater than any transition yet seen.

Of course, the job of controlling a heterogeneous, widely dispersed, yet globally interconnected system like the electric grid poses serious technological problems. Yet it will prove even more complex and difficult to control for optimal efficiency and maximum benefit to ultimate consumers while still allowing all the various business components to compete fairly and freely.

Similar needs exist for other infrastructures, where future advanced systems are predicated on the near-perfect functioning of today's electricity, communications, transportation and financial services. But in the electric industry in particular – so necessary to our quality of life, economy and security – uncertainties persist and are growing at nearly every scale, including operational, policy, investment and market, education, and talent pipeline. Industry leadership must focus increasingly on managing uncertainties in wide-ranging areas – from policy and politics to environmental factors, from investment to business model innovation, and from disruptive technologies to workforce and talent development.

The most visible parts of these problems stem from years of inadequate investment in the infrastructure, R&D, and associated human capital. The reason for this neglect is caused partly by uncertainties over what government regulators will do next and what investors will do next.

As ComEd CEO Anne Pramaggiore notes, "Today's regulatory framework is keeping us locked into the 20th century."

What has caused this hindrance in development? Quite simply, we've wasted 15 years arguing the roles of the public and private sectors while our global competitors adapt and innovate. We need to renew public/private partnerships, cut red tape and reduce the cloud of uncertainty surrounding the return on investment (ROI) of modernizing and upgrading infrastructure.

As the digitization of society continues to expand, and as environmental issues grow in urgency, it becomes increasingly critical that we make investments in development if we want to accommodate the growing need for electricity. In fact, it is projected that the world's electricity supply will need to triple by 2050 to keep up with demand.

Our approach so far – to deal with outages by simply coping – is ultimately a defeatist strategy.

Let's frame the issues. As I see it, here are the top 10 drivers for change in the electric power sector, in no particular order:

- Acceleration of efficiency (energy intensity dropping 2%/yr.);
- Distributed generation and energy resources (DG & DERs), including energy storage & microgrids;
- More cities interested in charting their energy future;
- District energy systems;
- Smart Grid;
- Electrification of transportation;
- New EPA regulations, such as for greenhouse gases under Section 111(d) of Clean Air Act;
- Demand response (and 3rd-party aggregation of same);
- Combined heat & power (CHP), plus waste heat recovery; and
- The increasingly interstate and even trans-national nature of utilities (and contractors too, which leads to security concerns).

These drivers in turn lead to some important questions, both for the utility, as a business, and for regulators, as makers of policy:

- What business models may develop, and how will they successfully serve both upstream electricity market actors and energy consumers?

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■ What effects could these new business models have on incumbent utilities, and what opportunities may exist for other industry sectors to capitalize on these changes?

■ How will regulation need to evolve to create a level playing field for both distributed and traditional energy resources?

■ What plausible visions do we see for the future of the power sector, including changes for incumbent utilities, new electricity service providers, regulators, policymakers, and consumers?

■ What measures are practical and useful for critical infrastructure protection (CIP) and the security of cyber physical infrastructure?

To answer these questions, we must address a number of new challenges, such as how to integrate large-scale stochastic (uncertain) renewable generation, electric energy storage, distributed generation, plug-in hybrid electric vehicles, and demand response (smart meters). We must also realize methods to deploy and integrate new synchronized measurement technologies, new sensors, and new system integrity protection schemes.

What follows is a look at where we are, and what may lie ahead, with a focus on the (1) the scope of the problem, (2) regulatory reform initiatives now underway, and (3) how to go about rethinking the business models that might evolve. (In a future issue, I will follow up with an in-depth look at some related challenges, such as privacy rights and cyber security.)

But before going further, please allow me to thank the many industry leaders who have provided helpful feedback and insightful analyses, including several colleagues at the IEEE Smart Grid initiative, Energy Thought Summit (ETS), U.S. DOE, EPRI, EEI (Edison Electric Institute), NRECA (National Rural Electric Cooperative Association), various municipal utilities, FERC (Federal Energy Regulatory Commission), NARUC (National Association of Regulatory Utility Commissioners), NERC (North American Reliability Corporation), PUCs (state utility commissions), and elsewhere.

Overcoming Defeatism

Consider the factors that are hindering improvements to the nation's electric grid.

First, on any given day, there are half a million people in America who must go without electricity for two or more hours per day. The number of weather-caused, major outages in the U.S. has risen since the 1950s, from between two and five each year by the 1980s to 70–130 between 2008 and 2012. Two thirds of weather-related power disruptions have occurred in the past five years, affecting up to 178 million customers (meters), as changing weather patterns impact aging infrastructure. However, outages are not always in the same location, and because of that, we have a very short attention span.

Second, there is a lack of leadership in the public and private sectors. There is a lot of uncertainty, and that hinders the development of the smart grid. Congress should incentivize investment in the infrastructure. We can create jobs in this area – very high-paying jobs. Just to integrate distributed resources such as wind power, we need to add about 42,000 miles of high-voltage line, and that would create over 210,000 jobs.

Third, there is a divide between federal jurisdiction and local jurisdiction. The high-voltage grid, for the most part, is under federal jurisdiction, but the distribution systems are under the local jurisdiction – mostly public utility commissions. That basically kills the incentive for any utility group to do regional work and upgrade on a regional basis. We need coordination in the investment in the grid and in the research and development areas.

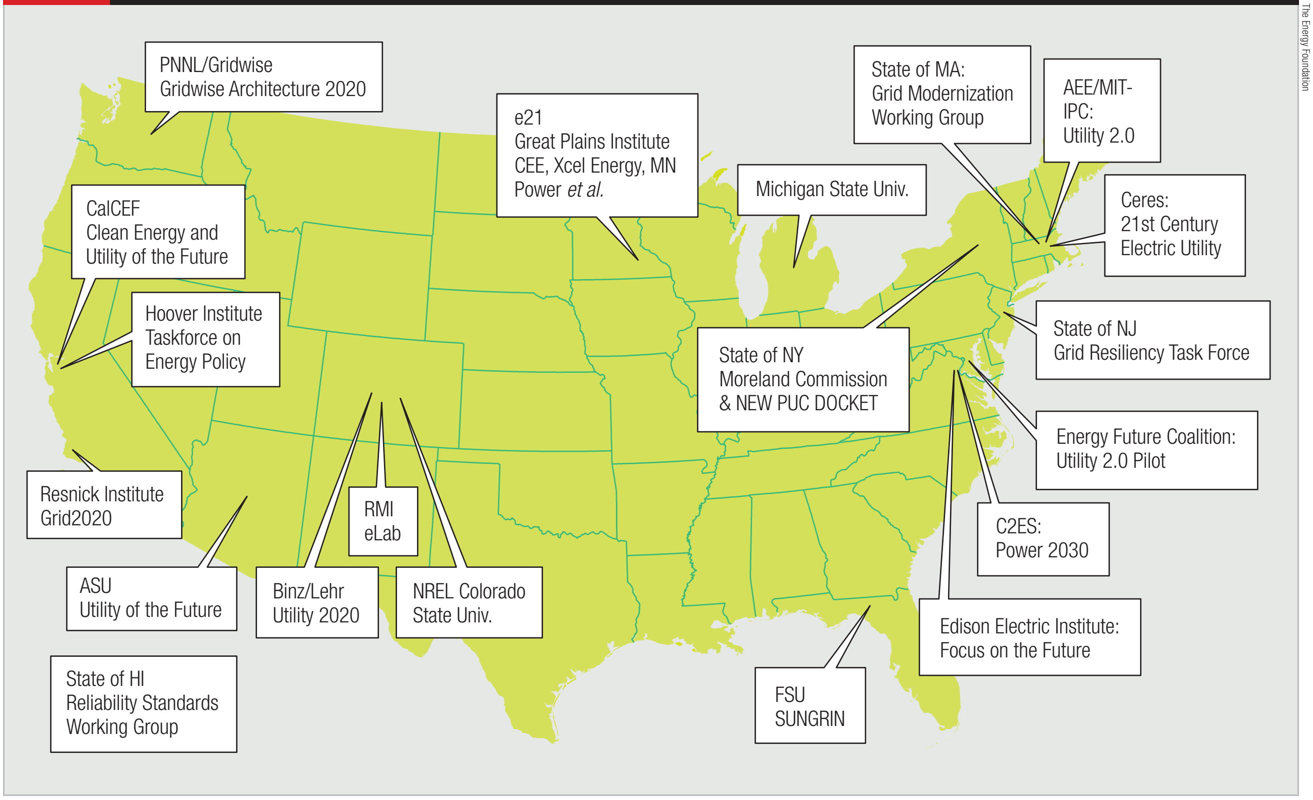
Regulatory restructuring, though well-intentioned, has not yet not fully answered the problem of lagging infrastructure investment. In fact, for the power industry in the United States, direct infrastructure investment has declined in an environment of regulatory uncertainty because of deregulation, and infrastructure R&D funding has declined in an environment of increased competition because of restructuring. Electricity investment was not large to begin with. Presently the power industry spends a smaller proportion of annual sales on R&D than do the dog foods, leather, insurance, or many other industries – less than 0.3 percent, or about $600 million per year. The electric power sector is second from the bottom of all major U.S. industries in terms of R&D spending as a percentage of revenue, exceeding only the pulp and paper industry. In the electric power sector, R&D represented a meager 0.3 percent of net sales in the six-year period from 1995 to 2000, before declining even further to 0.17 percent from 2001 to 2006. The pet food industry, hotel industry and the insurance industry all invest in R&D at a higher rate than electrical power.

A self-healing grid isolates problems as they occur, before they snowball into major blackouts.

Growth, environmental issues, and other factors also contribute to the difficult challenge of ensuring infrastructure adequacy and security. New environmental considerations, energy conservation efforts, and cost competition require greater efficiency throughout the grid. Not only are infrastructures becoming more complexly interwoven and more difficult to comprehend and control, there is less investment available to support their development.

And the most significant environmental issue concerns the development of renewable and sustainable energy recourses. For example, much of the renewable energy and natural gas potential in the United States is located in areas that are remote from population centers, lack high demand for energy, and are not well connected to our national infrastructure for transmission of bulk

Fig. 1 **Regulatory Reform Efforts**



Source: The Energy Foundation

electrical power. The recent expansion of natural gas production in the U.S. has also affected development of the grid. To achieve public policy objectives, sufficient transmission capacity must link new natural gas generating plants, on-shore or off-shore wind farms, solar plants and other renewables to customers if those resources are to serve the energy needs of homes and businesses, and have the potential to replace significant portions of the oil used today in vehicle transportation.

New transmission will play a critical role in the transformation of the electric grid to enable public policy objectives, accommodate the retirement of older generation resources, increase transfer capability to obtain greater market efficiency for the benefit of consumers, and continue to meet evolving national, regional, and local reliability standards. With a stronger and smarter grid, 40 percent of our electricity in the U.S. can come from wind by 2030.

Meanwhile, electricity needs are changing and growing fast. Tweeting, and the devices and infrastructure needed to operate the underpinning communication network, data centers and storage alone adds more than 2,500 megawatt hours (MWh) of demand globally per year that did not exist five years ago. Kilowatt hour (kWh) is commonly used by power companies for billing, since the monthly energy consumption of a typical residential customer ranges from a few hundred to a few thousand kilowatt hours. One MWh is equal to 1,000 kilowatts of electricity used continuously for one hour. One MWh is the amount of electricity used by approximately 330 homes in one hour. On average 2500 MWh is equivalent to the electricity used by about 825,000 homes. Factor in Internet TV, video streaming, online gaming and the digitization of medical records, and the world's electricity supply will need to triple by 2050 to keep up.

The world's electric supply will need to triple by 2050.

These developments point out the many weaknesses in the current state of our electric grid. But our primary strategy till now for dealing with these problems – a strategy that is best described as simply coping – is ultimately a defeatist strategy.

Defining the Self-Healing Grid

What, then, is a smart, self-healing grid? And why is it needed? A self-healing grid uses digital components and real-time communications technologies installed throughout a grid to monitor the grid's electrical characteristics at all times and constantly tune itself so that it operates at an optimum state. It has the intelligence to constantly look for potential problems caused by storms, catastrophes, human error or even sabotage. It will react to real or potential abnormalities within a fraction of a second, just as a military fighter jet reconfigures itself to stay aloft after it is damaged. The self-healing grid isolates problems immediately as they occur, before they snowball into major blackouts, and reorganizes the grid and reroutes energy transmissions so that services continue for all customers while the problem is physically repaired by line crews.

A self-healing smart grid can provide a number of benefits that lend to a more stable and efficient system. Three of its primary functions include**:**

- **Real-time monitoring and reaction,** which allows the system to constantly tune itself to an optimal state;
- **Anticipation**, which enables the system to automatically look for problems that could trigger larger disturbances; and
- **Rapid isolation**, which allows the system to isolate parts of the network that experience failure from the rest of the system to avoid the spread of disruption and enables a more rapid restoration.

As a result of these functions, a self-healing smart grid system is able to reduce power outages and minimize their length when they do occur. The smart grid is able to detect abnormal signals, make adaptive reconfigurations and isolate disturbances, eliminating or minimizing electrical disturbances during storms or other catastrophes. And, because the system is self-healing, it has an end-to-end resilience that detects and overrides human errors that result in some of the power outages, such as when a worker error left millions of California residents without electricity in September 2011.

And how does a smart self-healing grid provide benefits to energy consumers?

Beyond, managing power disturbances, a smart grid system has the ability to measure how and when consumers use the most power. This information allows utility providers to charge consumers variable rates for energy based upon supply and demand. Ultimately, this variable rate will incentivize consumers to shift their heavy use of electricity to times of the day when demand is low and will contribute to a healthier environment by helping consumers better manage and more efficiently use energy.

Nevertheless, despite these advantages, a collection of various independent technologies will be required to transform our current infrastructure into a self-healing smart grid.

The ideal smart grid system consists of microgrids, which are small, mostly self-sufficient power systems, and a stronger, smarter high-voltage power grid, which serves as the backbone to the overall system.

Upgrading the grid infrastructure for self-healing capabilities also requires replacing traditional analog technologies with digital components, software processors and power electronics technologies. These must be installed throughout a system so that it can be digitally controlled, which is the key ingredient to a grid that is self-monitoring and self-healing.

Much of the technology and systems thinking behind self-healing power grids comes from the military aviation sector, where I worked for 14 years on damage-adaptive flight systems for F-15 aircraft, optimizing logistics and studying the survival of squadrons and mission effectiveness. In January 1998, when I joined the Electric Power Research Institute (EPRI), I helped bring these concepts to electricity power systems and other critical infrastructure networks, including energy, water, telecommunications and finance. Following the September 11, 2001, terrorist attacks, resilience and security has become even more important.

Microgrids: A Growing Role

Smart microgrids represent a key a growth area in recent years and will no doubt play a growing role in meeting local demand, enhancing reliability, and ensuring local control of electricity – at least where financial viable.

Microgrids are small power systems of several megawatts (MW) or less in scale with three primary characteristics: distributed generators with optional storage capacity, autonomous load centers, and the capability to operate interconnected with or "islanded" from a larger grids. Storage can be provided by batteries, super-capacitors, flywheels, or other sources.

Like a moon shot – and it will cost $25 billion a year for 20 years – this is just the sort of thing Americans do best.

Microgrids can serve as ideal platforms for realizing combined goals of a smart grid, including reliability, integration of renewables, diversification of energy sources, and flexible demand response. Because of their scale, they facilitate systematic, yet innovative, approaches to solve local as well as global energy needs. They can also provide facilities and communities a certain level of independence from grid disruptions while providing grid operators and utilities an additional resource for improving their operations.

In some respects, microgrids can be significantly more complex. For example, they might include DC elements and inverters for conversion. They can also exert greater control over a wider variety of loads, and the connection with the grid can be flexible. On the last point, microgrids can enable uninterrupted operation where grid supply might be unreliable. In this case, the islanding capability of a microgrid comes into play. Intelligent microgrids have to optimally manage interconnected loads and distributed energy resources (including renewables) both in grid-connected and islanded modes.

An autonomous microgrid is a microgrid operated and coordinated by intelligent automatic controls without significant reliance on human intervention. The principle of locality for an autonomous microgrid implies that it operates with maximal independence from other microgrids (*i.e.*, minimal

Fig. 2 **Utility of the Future: Status of Various Initiatives**

Utility	Scope of the Utility of the Future Initiative
Ameren	Initial exploration/learning
Duquesne	Assessment & planning
Duke	Assessment & technology testing
Xcel	Policy engagement
Portland General Electric	Differentiated customer services re: BUGs
Puget Sound	Grid storage
Dominion	Advanced grid modernization
National Grid	NY REV scope
ConEdison	NY REV scope
Iberdrola-US	NY REV scope
Other NY utilities	NY REV scope
OG&E	Customer service and DR as a resource
NV Energy	Customer service and DR as a resource
PG&E	Range of CA activity related to grid modernization, DER integration and use as resource
SDG&E	Range of CA activity related to grid modernization, DER integration and use as resource
SCE	Range of CA activity related to grid modernization, DER integration and use as resource
APS	Utility investment in rooftop solar PV for customers
Tuscon Electric	Utility investment in rooftop solar PV for customers
Centerpoint	Various customer market facilitation services - shopping portal
HECO	Range of HI activity related to grid modernization, DER integration and use as resource
Southern	Just started

interdependencies among microgrids) subject to meeting its goals for reliability and cost limits on storage. A cellular power network is a large-scale dynamic-topology power network composed of autonomous microgrids that each exhibit self-similar properties to enable scale-up.

Already we can see many localities starting to build microgrids, to serve campuses, communities and cities. Many of those microgrids will draw their power from locally available and preferably renewable sources like wind and photovoltaics. Microgrids can be almost entirely self-sustaining. In fact, they can produce as much energy as they consume and generate "zero net" carbon emissions. We have shown this at the University of Minnesota, where we are building and demonstrating a microgrid on one of our campuses. Using biomass from nearby farms, as well as solar and wind resources, it will soon be energy-self-sufficient. It has been zero-net-carbon since 2008.

The microgrid concept eventually may be extended to higher voltage levels, to create self-contained, self-sufficient systems.

Storage: The Missing Link

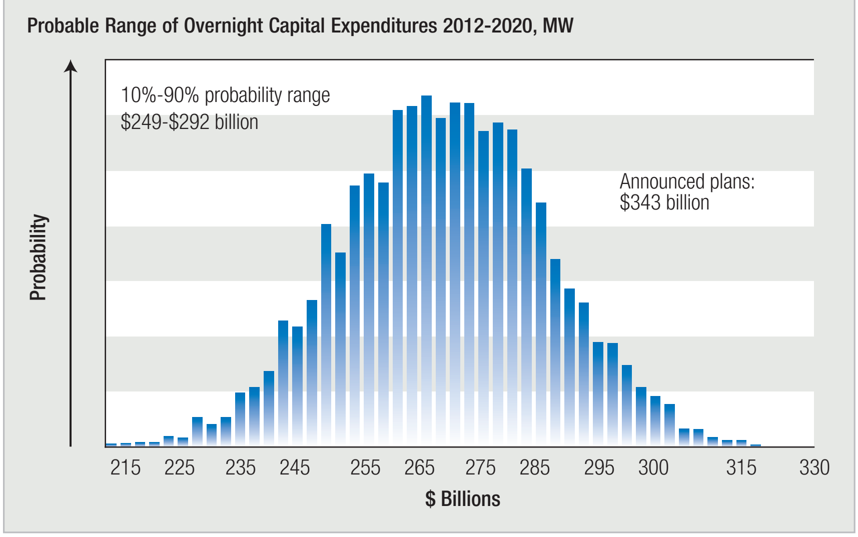
The development and deployment of bulk energy storage will also play a key role in supporting the power delivery system infrastructure needed for consumer services and in enabling the integration of intermittent renewable sources throughout the electric grid.

Without an "inventory" to access, utilities have little flexibility in managing electricity production and delivery. Likewise, intermittent renewable resources – such as solar and wind – cannot be relied upon for hourly electricity supply. Although some commercially-proven technologies can store electricity by converting and storing it in another energy form – such as in flywheels, pumped storage, and batteries – only 2.5 percent of North American generation capacity, for example, uses such plants. That is because most storage options (except pumped-hydro and compressed air) remain relatively unproven. Also, their value propositions also are complex and poorly understood, while the uncertainties of changing regulatory rules makes storage options too risky for most investors.

The total price tag for the U.S. could approach $25 billion a year, for 20 years.

Public and private organizations need to collaborate to analyze the costs and benefits of existing storage options, including pumped hydro, compressed air, and battery plants. Additional recommended work includes considering the potential

FIG. 3 UTILITY CAP-EX SPENDING



return-on-investment (ROI) of enhancing existing storage options and building new ones. Achieving these goals will involve the development of sophisticated tools to predict the costs of producing large-scale storage systems 5-20 years in the future. It will also require new models to simulate the economic characteristics of future power delivery system conditions to predict the potential benefits of storage options to generation, transmission, and distribution owners as well as end-use consumers. Once accurate cost, benefit, and ROI estimates are available, the next step will be a series of research and development projects designed to build large-scale, lower-cost storage modules and demonstrate them at appropriate utility sites under real-world conditions. During these demonstrations, the collection and analysis of cost and performance data will be a high priority. To address investor concerns about existing or new storage options, high-end communications to key stakeholders will be essential.

Reliability and Resiliency

Building a smart and self-healing intelligent grid also fits in well with hardening the grid and making it more resilient, all to mitigate the impacts of extreme weather events.

Hardening, for instance, might mean that substations in flood-prone areas should be optimized for location and design and construction standards against floods – especially for underground substations in, say, New York City. The design standards for feeders should be improved to the level applied to higher voltage lines. Selective undergrounding for critical lines may be cost effective. New materials can make power poles sturdier and cables more resilient.

For reliability and resilience, smart grid technologies will help. The application of sensors, from phasor measurement units in the substation, down the feeder to smart meters at the premise will provide rich data for monitoring performance and the impacts of anomalous events. The overlay of a digital communications network to augment traditional SCADA systems will convey that data to distributed intelligence as well as operators and carry commands back to devices in the field.

Designing distribution networks in loop, rather than radial, arrangements allows greater sectionalizing, which in turn improves the specificity of fault detection, isolation and restoration (FDIR). That will keep the power on for unaffected businesses and homes and allow utilities to focus on damaged portions of the network. Automated switches and reclosers can speed the FDIR response beyond human capabilities and that will produce the self-healing abilities that characterize smart grid.

In addition, it would behoove communities to prioritize power reliability for public infrastructure such as street lights, shelters, police, fire, and hospital facilities. This would help maintain civil order and essential operations under chaotic conditions. Microgrids and distributed generation could "island" large end-users to maintain their capabilities when the grid fails. Microgrids also enable centralized grids to shed loads. Homes and businesses could also use distributed generation and energy storage to restore power. In time, home energy management systems will prioritize home loads for everyday efficiencies and in emergencies.

Economic analyses demonstrate that investments in power infrastructure deliver value that exceeds costs, producing greater reliability and improved resiliency that results in sustained economic growth and job creation. For individual consumers, less extensive, shorter outages from extreme weather and improved, everyday reliability are likely to be highly valued in an increasingly digital society. Economically, the societal payback for each dollar invested ranges from $2.80 to $6, based on my own research as well as work by EPRI.

Let's address traditional reliability indices. Using IEEE models, as well as my experience at military bases with 20,000-50,000 inhabitants and cities with 500,000 to 1 million population, we've seen improvements in SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index) of 12-14 percent at the low end, and 30-40 percent at the high end. In a conservative forecast, CAIDI (Customer Average Interruption Duration Index) holds steady and at the higher end it can be improved 17-18 percent.

The proper measure of grid modernization is how these indices improve for blue sky days, not during anomalous events such as Sandy. So preparing for another Sandy pays dividends in reliability and resiliency under typical conditions.

Fig. 4 **Sample Drivers**

State of the drivers	Electricity demand	Natural Gas*	Environment and energy policy
Low	Continuous decline in electricity supplied from grid resources leading to negative growth in future years	Sustained price under $4/million Btu	Limited to laws or regulations already in place
Medium	Flat load growth	Continued volatility and uncertainty in price ranging from $4-7/million Btu	Moderate increase of laws and regulations (focused on air, water, waste)
High	Robust load growth approaching 1-2% per year	Price > $8 with levels reaching >$10 at times	Expansive new set of laws and regulations (including clean energy or GHGs)

* In this table, these prices are based on U.S. Henry Hub Prices.

And utilities along the East Coast are now actively considering these measures.

For example, Consolidated Edison (ConEd) Co. of New York City and Public Service Electric & Gas (PSEG), based in Newark, New Jersey, both saw extensive damage to their grids and extended outages for their customers, but are taking action to safeguard their grids from future events.

ConEd has presented its "Post Sandy Enhancement Plan" to spend $250 million on a hardening program for Orange and Rockland counties that relies on many measures I've outlined. In contrast, PSEG has floated a nearly $4 billion proposal (the "Energy Strong Program Petition") for a five-year plan, which must be approved by the New Jersey Board of Public Utilities. PSEG's proposal includes budgets of $2.8 billion for electric infrastructure and $1.2 billion for natural gas.

In general, most fully funded smart grid-focused roadmaps could be accomplished in one to two years, with systems integration to achieve full value taking another year or two. Many of us are watching to see how ConEd's and PSEG's proposals are received.

Worldwide Efforts

Recent policies in the U.S., China, India, EU, UK and other nations throughout the world, combined with potential for technological innovations and business opportunities, have attracted a high level of interest in the smart grid.

Nations, regions, and cities that best implement new strategies and infrastructure may reshuffle the world pecking order. Emerging markets could leapfrog other nations.

United States. The U.S. Department of Energy's American Recovery and Reinvestment Act of 2009 (the stimulus bill) awarded the Office of Energy Efficiency and Renewable Energy $16.8 billion for its programs and initiatives. In addition, since 2009, the U.S. Department of Energy (DOE) and the electricity industry have jointly invested in 99 Smart Grid Investment Grant (SGIG) projects to modernize the electric grid, strengthen cybersecurity, improve interoperability and collect an unprecedented level of information on smart grid operations. The stimulus bill provided $3.4 billion in federal funding, and project recipients have invested an additional $4.5 billion in private funding, for a total SGIG budget of $7.9 billion. The 99 projects involve 228 participating utilities and other organizations, in every region of the country and almost every state.

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China. The world's now largest economy has invested $7.3 billion, and will spend $96 billion in Smart Grid technology by 2020. Yet China's energy needs will double by 2020. Many changes will happen in the homes themselves. As of 2015, China is thought to account for some 18 percent of global smart grid appliance spending.

South Korea. Investment here has reached nearly $1 billion. A $65 million pilot program on Jeju Island is implementing a fully integrated grid for 6,000 homes, a series of wind farms, and four distribution lines. Its leaders plan to implement smart grid infrastructure nationwide by 2030.

Brazil. Brazil will see 60-percent growth in electricity consumption between 2007 and 2017, with a 16-34 percent increase in renewables from hydroelectric, biomass, and wind. However, Brazil has an aging grid that is currently a one-way power flow (but needs to move in two directions). The Regulator is pushing for mandatory replacement of 65 million meters starting in Q4 2012, and the new regulation of time of use (TOU) tariffs for residential customers, aiming to reduce peak load. Utilities, meanwhile, are launching several smart metering pilots and distribution automation projects.

Mexico. Comisión Federal de Electricidad (English: Federal Electricity Commission), or CFE, is acquiring a pilot for 23,000 meters in order to better understand the technology and prove the benefits. After CFE took over Luz y Fuerza del Centro concession area, the ultimate goal is to achieve higher quality/reliability indicators in the Mexico City metro area.

The Domestic Outlook

Considering the whole North American system, to address energy security and integration of available generation resources, as well as for increased environmental, economic and national security, our first strategy should be to expand and strengthen the transmission backbone by adding about 42,000 miles of high-voltages transmission lines to the existing 450,000 miles. This expansion will cost about $82 billion, and will provide 210,000-214,000 sustainable good-paying jobs, and will result in about 40% of electricity to come from integration of wind resources in the United States. Most of that new transmission will consist of HVDC lines. Locally, highly efficient microgrids combining heat, power and storage systems will be built out over twenty years, at a cost of $17-24 billion annually. At all levels, smarter grids will come to have self-healing capabilities.

Overall, the cost of a smarter grid for the United States would depend on how much instrumentation is actually put in, such as the communications backbone, enhanced security and increased resilience. The total price tag ranges around $340 billion to $480 billion, which, over a 20-year period, would be something like $20 billion-$25 billion per year. But right off the bat, the benefits are $70 billion per year in reduced costs from outages, and during a year where there are lots of hurricanes, lots of ice storms, and other disturbances, that benefit even goes further. Currently, outages from all sources cost the U.S. economy somewhere between $80 billion to $188 billion annually. Costs of outages reduced by about $49 billion per year, and reduced CO_2 emissions by 12-18% by 2030. In addition, it would increase system efficiency by over 4% – that's another $20.4 billion a year.

The costs cover a wide variety of enhancements to bring the power delivery system to the performance levels required for a smart grid. They include the infrastructure to integrate distributed energy resources and achieve full customer connectivity but exclude the cost of generation, the cost of transmission expansion to add renewables and to meet load growth and a category of customer costs for smart-grid-ready appliances and devices. Despite the costs of implementation, investing in the grid would pay for itself.

But this is also about 1) increased cyber/IT security, and overall energy security, with security built in the design as part of a layered defense system architecture, and 2) job creation and an economic benefit. With the actual investment, for every dollar, the return is about $2.80 to $6 to the broader economy. And this figure is conservative.

Can we foresee a widespread overhaul of the electric grid in America's future?

If you look at a macro picture, you see that we also succeed whenever we make this type of a big advancement, such as the moon shot or the national highway system, and when we put the American will, know-how, and passion behind this sort of audacious goal.

Finally, to modernize the whole end-to-end system, the smart grid represents a remaking of the electric power system encompassing all aspects of generation, delivery, and consumption. Benefits will accrue to individuals, societies, and industry: better use of renewable sources, reduction in carbon emissions from fossil plants, improved efficiencies across the power system, broad-based integration of electric and plug-in hybrid vehicles, real-time feedback to consumers on their electricity consumption, improved grid reliability, and more.

With a stronger and smarter grid, 40 percent of our electricity in the U.S. can come from wind by 2030.

But several challenges must first be addressed: Intermittent renewables and greater variability in load profiles will result in high uncertainty in both generation and consumption. Dynamic pricing and demand response will intricately couple economic factors and power flow. With communication technologies providing a system-wide integration infrastructure, the smart grid will represent a prototypical "system of systems." Multiple and often conflicting criteria will need to be coordinated: profits, grid reliability, environmental impacts, equipment constraints, and consumer preferences. Environmental and energy policy need to be supportive of this transformation.

The economic benefits of a modernized grid will accrue as investments are made. Indeed, in my view, our 21st century digital economy depends on us making these investments, in a risk-managed and systematic way.