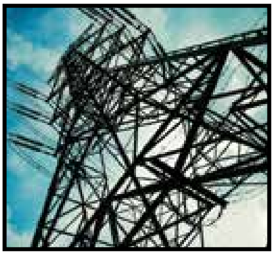
2013 ENERGY POLICY FORUM

The Future of the U.S. Electricity Sector



Bill Dickenson & Phil Sharp, Co-Chairs
Dave Grossman, Rapporteur

THE ASPEN INSTITUTE
ENERGY & ENVIRONMENT
PROGRAM

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Foreword

An invited group of energy leaders and policy experts discussed a range of issues affecting the electricity sector at the Aspen Institute's 34th annual Energy Policy Forum, held in Aspen July 3-7, 2013. Participants in the 2012 Forum strongly suggested innovation as a central topic for this year's Forum, and subsequent events, particularly in the wake of Hurricane Sandy, suggested the inclusion of reliability, resilience, and cybersecurity as topics of discussion.

As in previous years, the format relied heavily on dialogue to explore commercial and public policy issues at the intersection of energy, the economy, and the environment. Short introductory presentations launched each half-day session, and a spirited, off-the-record discussion followed. The diverse participants brought a variety of perspectives and areas of expertise to the table. The Forum's rule preventing quotations of anyone by name allowed for a candid and spirited discussion, and the collegial atmosphere encouraged continuing conversations outside the meeting room.

The dialogue was chaired by Bill Dickenson, Energy Practice Leader at Navigant, and Phil Sharp, President of Resources for the Future. The highly qualified group of session chairs and speakers provided a wealth of information and a variety of perspectives, and the diverse expertise of a particularly well-qualified group of participants contributed substantially to the richness of the dialogue.

The Institute acknowledges and thanks the following Forum sponsors for their financial support. Without their generosity and commitment to our work, the Forum could not have taken place.

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I also thank Dave Grossman, who served as rapporteur. While no document can capture the richness of the discussion occurring over several days, he captured the key points of a fast-moving conversation and distilled them into this summary report.

Nikki De Vignes admirably handled the administrative preparations and arrangements in Aspen. Her unfailing good humor and attention to detail contributed to a pleasant and smoothly run meeting. Tim Olson provided his usual strong support. Along with the participants, I am grateful for their conscientious efforts.

The report is issued under the auspices of the Aspen Institute, and the chairs, speakers, participants, and sponsors are not responsible for its contents. It is an attempt to represent ideas and information presented during the Forum, but all views expressed were not unanimous, and participants were not asked to agree to the wording.

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The Future of the U.S. Electricity Sector

Dave Grossman
Rapporteur

Executive Summary

The future of the U.S. electricity sector is hard to foresee – and it is never wise to overpay one's fortune tellers – but there appear to be some key trends and technologies that may reshape future electricity markets and determine the innovativeness, resilience, security, and global competitiveness of the sector. Discussions of the sector's past, present, and future formed the heart of the 2013 Aspen Institute Energy Policy Forum. This report summarizes and organizes some of the key insights from those discussions.

Looking back over the past decade, it is striking how many of the developments in the energy sector were not predicted, including the U.S. shale gas boom, the massive price drop for solar photovoltaic (PV) modules, and the lack of a big build-out of coal-fired power plants in the United States. With due respect, therefore, for the limits of prediction, the U.S. electricity sector nevertheless seems likely to encounter a few powerful trends over the next 5-10 years. The sector is likely to see continued disintermediation, anemic or negative demand growth, and broader challenges to the traditional utility business model from distributed generation. Smart electricity networks and "big data" analytics are likely to create vastly enhanced capabilities and significant value for both utilities and end-use customers, while integrating the physical and digital networks in the United States may similarly produce tremendous savings and benefits. Physical environmental constraints such as water scarcity and land availability are likely to affect sector operations and generation choices. The policy and regulatory frameworks within which utilities operate are likely to start shifting to new approaches designed to further minimize electricity costs, maximize reliability, and minimize environmental damage.

In this near-term future, there are some technologies that could prove to be very important. Low solar PV prices and new financing models that reduce up-front costs have already led to a solar rooftop boom in the United States – a trend that is likely to continue even after massive polysilicon overcapacity and U.S.-China and EU-China trade disputes are considered. Energy storage technologies, which are often cited as potential game-changers, can help with renewables integration while also providing a sweeping range of other services. Carbon capture, utilization, and storage (CCUS) and new nuclear power have both been somewhat overlooked in the United States recently as opportunities for low-carbon power, but a few projects are still advancing (and many more are in China). Other technologies (e.g., geothermal energy, energy efficiency) could also be game-changers on the path to decarbonizing the electricity sector.

Achieving this decarbonization will rely heavily on innovation, in which both governments and industry play vital roles. Virtually all energy technologies have been (and will be) developed with substantial government support, whether in the form of direct financial support, public procurement (especially procurement on the cutting edge of technology), government research and development (R&D), assistance in bringing technologies to market, cost recovery and pricing decisions by public utilities commissions (PUCs), or other government policies that are technology forcing, enable competition, provide clear and efficient price signals, and otherwise create conditions that promote innovation. While the electricity sector has generally been one of the least innovative sectors in the economy, vendors, the Electric Power Research Institute (EPRI), electric co-ops, and some utilities are investing in R&D and assessing the viability of technologies. Utilities may want to boost their R&D efforts – and engage with regulators regularly while doing so – with a focus on innovations in generation, customer end-use, and system optimization.

Beyond decarbonization, innovation can also play a role in enhancing the resilience, reliability, and security of the electricity system. Natural disasters, physical attacks, and cybersecurity threats have heightened concerns about the ability of the system to prevent, withstand, and recover from emergencies. Utilities and other providers have been working to harden the physical grid itself, put procedures and plans in place to prepare for and respond to events, and move to a smarter, more distributed, more dynamically responsive grid. Electricity providers and government agencies have also been working to protect the grid from cyberattacks by hacktivists, industrial competitors, and foreign nations (especially China). Cybersecurity strategy has focused on multi-layer protection, including local and organizational policies and controls, information sharing, analytics, trainings and exercises, public-private partnerships, and national-level tools.

In discussions on the future of electricity (as well as cybersecurity, climate change, and many other topics), China now looms large. China is increasingly a source of capital and a test bed for technological development, while also enabling mass production that has brought the costs of energy technologies (particularly solar PV) way down. China has become the world's top producer of solar PV and wind turbines, though massive overcapacity is now bankrupting manufacturers. China also consumes almost as much coal as the rest of the world combined and is initiating a number of CCUS projects – in which U.S. utilities are engaging to get experience they cannot get at home. U.S. companies are going to China to construct large commercial nuclear energy projects, too, and China has become the lead developer of Generation IV nuclear energy projects. Internally, China's power sector may be poised for reform, as Chinese leadership appears committed to restructuring the economy away from energy-intensive heavy industry and toward light manufacturing and services. All in all, China has become a world leader in the energy sector, with implications for U.S. competitiveness, innovation, and technological development and deployment.

Trends Likely to Affect the Industry

The future of the electricity sector – even over just the next 5 to 10 years, much less over the next few decades – is difficult to foresee. The past decade usefully underscores this reality.

Over the last decade, very significant changes and technological advances occurred in the U.S. energy sector, driven by four major developments:

- massive increases in the price of natural gas, then oil, at the beginning of the decade;
- incredible entrepreneurial risk-taking in natural gas, solar, and elsewhere;
- the payoff from prior decades of major public and private investment in technologies (e.g., shale gas); and
- a considerable amount of state and federal policymaking.

Perhaps the most striking phenomenon of the past decade, however, was how much was not predicted. Conventional prognostication missed the oil and gas price increases, shale gas development and gas price decreases, cost reductions in solar, new nuclear power plant construction, and the shifting politics of energy. Similarly, things that were expected to happen – a major new fleet of U.S. coal-fired power plants, meeting the market mandate on cellulosic biomass, adoption of a major greenhouse gas reduction plan – did not, in fact, happen. It was a decade of huge change and big surprises.

Recognizing that the future is hard to see, there are nevertheless several trends that seem to have the potential to reshape energy markets, including those described below.

Challenges to the Utility Business Model

The model of the impregnable vertically-integrated utility monopoly – controlling generation, transmission, and distribution – has largely ceased to exist. On the generation side, the Public Utility Regulatory Policy Act (PURPA), the rise of independent power producers, and other developments have translated into hundreds of thousands of megawatts of generation built by third parties. Transmission, in all but a few states, is controlled by regional organizations. The walls are now starting to come down with respect to distribution as well, thanks to burgeoning solar power on rooftops, other distributed generation, microgrids, and other developments that are hastening disintermediation (i.e., the elimination of the middle man). These crumbling walls raise fundamental questions about the role of utilities going forward and about who will bear the costs of the electricity system.

The interplay of disintermediation and anemic demand growth spells trouble for the current utility business model. Growth in the industry has been slowing for a long time, from a 10% growth rate in the 1950s to 5% in the 1970s to 2.5% in the 1990s. If solar power penetrates to the extent anticipated, and if residential usage keeps declining (e.g., due to appliance standards), the growth rate may be 1% or less (or even negative) going forward. Industry has to make long-term investments in the system even while ever-increasing numbers of people are using fewer kilowatt-hours from that system.

The existing rate structure makes this situation untenable. The system costs are being spread over a smaller pool of ratepayers, which means rates are going up for the people who cannot afford rooftop solar. As utilities confront the increased trend of distributed generation, rate structures may need to change to allow utilities to earn what they need to in order to provide grid reliability and universal service. Increased use of distributed energy resources and demand response could also spur challenges to how utilities price their product for customers, with questions about the wisdom of volumetric pricing compared to more dynamic pricing and about the viability of the baseload-shoulder-peaking paradigm in a more disaggregated, heterogeneous system.

Data & Smart Electricity Networks

The digital revolution is accelerating into the electric utility sector, changing its ability to manage the flow of electrons and massive amounts of data. As information technology keeps changing and permeating the electricity sector, the future may well be about cloud-scale computing infrastructure, "big data" analytics, and human-computer interaction models. This "future" has, in fact, already begun. There are now several technological elements embedded in the system – such as smart meters, smart thermostats, and smart appliances – and the capabilities of data analytics are growing.

The current system has huge amounts of data underlying it, but those data are usually in silos. Looking across all the data silos, technology can aggregate the information, keep it current in real-time, subject it to deep analytics, reveal correlations and patterns, and graphically manifest results for utility operators and end-users. On the utility side, data analytics can help with identifying meters that do not work, identifying sources of electricity theft, directing grid investments to customers experiencing the most reliability issues, assessing asset health and maintenance, forecasting load, analyzing outages, optimizing voltage, segmenting customers, allowing for more precise vegetation management, and many other functions. For a 5-million-meter utility, the economic benefits of grid analytics could be on the order of $1.6 billion in annual recurring economic value. On the customer side, human-computer interaction models are increasingly important, explaining how much the customer has spent, how much has been saved, peak pricing, demand response opportunities, projected energy use, and the like. For both utilities and customers, information and grid analytics can reduce costs and save money.

Data, in fact, may now be among the sector's biggest assets, and there are even more IT innovations on the horizon that could be unbelievably disruptive. Accordingly, critical questions are starting to arise about how to integrate, connect, and manage the whole system, who will do it, who has access to all the data, and the purposes for which the data are used.

Systems Integration

The United States has not only rich digital networks, but also rich physical networks, including the power grid, natural gas pipelines, freight rail, and long haul trucking. These networks enhance national competitiveness. More than just isolated networks, however, we are increasingly seeing meshing of different networks – whether linking discrete physical networks or integrating digital and physical networks – to find synergies and produce tremendous savings and benefits. Systems integration may well be a key focus of the next decade, which will boost the need for more digital-mechanical engineers with an understanding of the blending of digital and physical. At the same time, integration of networks has to be done in the right way, so that the networks prop each other up to be robust and resilient rather than facilitate failures that can cascade across the linked systems.

Physical Constraints from Environmental Conditions

Another area of increasing importance going forward will be better optimizing energy systems for the natural systems on which they rely – such as water and land. The utility industry, for instance, cannot function without water, yet there are many areas in the United States experiencing stress with regard to water availability. The industry will need to consider new water-efficient processes and think about the water footprint of different types of generation sources. Similarly, the industry will need to begin thinking seriously about the land footprint of generation sources as well.

Policy & Regulation

Utilities face rising costs, declining demand, complicated new challenges, and new competition. In response, utilities could try to throw up regulatory barriers, make customers pay to leave the system, and seek to keep getting paid for what utilities used to do. This approach may buy a few years, but it is ultimately a recipe for disintermediation. Instead, utilities may need to play the role of system optimizer. However, we do not have a regulatory system today that can address highly variable renewables and highly manageable demand, maximize energy efficiency and demand response, and reward flexibility.

As utilities and regulators seek to minimize costs, maximize reliability, and minimize environmental damage, regulatory trends may begin to reflect some new approaches, potentially including:

- Moving away from input-based regulation (i.e., rate of return) to output-based regulation (i.e., performance-based). This has to be done carefully, though, as there are more ways to do performance-based regulation wrong than right.
- Setting standards with long time horizons and a steadily tightening signal, in order to provide certainty for businesses to make capital investments, investors to invest, and customers to change behavior. More broadly, there may be a move toward "investment-grade policy" that is stable and long-term.
- Structuring markets so that the supply side and the demand side can compete.
- Encouraging distributed energy resources and having a clear methodology for allocating benefits and costs.

- Exploring a staircase capabilities market, which involves opening finite markets for power with particular flexibility characteristics (e.g., ability to ramp fast) – rather than just having marginal cost pricing for everything.

- Optimizing operation of the grid (e.g., improving dispatch).

- Establishing pre-set siting criteria in order to get infrastructure built quickly in the right places.

In addition, the principle of internalizing energy externalities is clear, but the politics currently seem impossible for anything resembling a tax on carbon and other energy-related emissions. Nevertheless, state and national policies to address greenhouse gases and other pollution are increasingly prevalent and still in development, which could have significant impacts on the future of the sector.

Technologies That Could Have a Big Impact

We know a lot about how to decarbonize electricity and much less about how to decarbonize fuels, which means the electricity sector will have to do more than its share – achieving near-total decarbonization – if we aim to reduce greenhouse gas emissions 80% by 2050. Speed, cost, reliability, externalities, and changes needed in policies and business models will be among the key factors in determining how electricity gets decarbonized.

There are areas where some in the electricity industry believe a technological breakthrough or faster-than-expected market penetration of existing technologies could upset expectations the way shale gas has. (It should be noted, though, that shale gas issues are still unfolding, including potential restraints on production, build-out of infrastructure, its effect as an enabler of microgrids, and its role in the transportation system.) While several technologies (e.g., geothermal, fusion, energy efficiency) might be game-changers, solar power and energy storage have received significant attention recently. New nuclear power and carbon capture, utilization, and storage (CCUS), on the other hand, have generally received much less.

Solar

For solar to be a game changer, it has to be seen as a safe investment for private capital and a valuable resource for utility providers and customers. Already, solar is attracting many investors, experiencing sharp reductions in solar module costs, and showing promising value as part of the integrated resources needed to meet state renewable electricity mandates.

The substantial drop in solar module costs is driven in large part by massive polysilicon overcapacity and thus falling polysilicon prices. (Companies have made some manufacturing process improvements, but there is plenty more room for that.) Solar manufacturers are selling below their production costs, which is why we are seeing bankruptcies in the United States, China, Germany, India, and elsewhere. We are also seeing dumping charges, tariffs, and talk of trade wars, similar to the U.S.-Japan semi-conductor battle in the 1990s, which resulted not in memory chip prices going back up but in countries focusing on their competitive advantages. So, even if solar module prices rebound somewhat as overcapacity decreases, it is extremely unlikely that prices will go back to where they were. Rather, prices will simply go to where the surviving companies can actually make some money. On a Chinese module now, at a total price of 65 cents per watt, companies are losing about 19 cents; therefore, if prices go up to where companies can make money, we would probably be looking at a price around $1 per watt.

Low-cost PV and lower system costs (e.g., due to easier integration) could result in very affordable rooftop solar energy. There have been interesting developments recently in the distributed solar space, most notably with SolarCity, whose solar leasing business model is attracting a lot of attention and customers. The company also got Goldman Sachs to set up a lease fund for more than $500 million in solar projects and got Honda to offer SolarCity discounts to all of its customers. Solar has been moving from utilities to rooftops in part because of the benefits of selling solar power against the retail margin instead of the wholesale margin.

Energy Storage

Energy storage is often touted as a potential game-changer and is already making strides in the market. The first movers have generally been focused on areas like specialty devices (e.g., electric gate openers), island grids (particularly with renewables integration), and integration with rooftop solar systems.

There are several available energy storage technologies, including batteries, flywheels, thermal storage, compressed air storage, and pumped hydro. Most interface with an AC transformer system to move power on and off the grid. Energy storage systems can be applied to meet load duration needs ranging from seconds to hours. Storage today is probably more compatible in terms of flexibility and cost-competitiveness with solar than with wind, i.e., in the space of two hours or less of storage.

Energy storage still faces a range of challenges. For one thing, storage can be expensive, though it may not be fair to directly compare the costs of storage to the costs of generation. In addition, a lot of the protocols and signals that get sent by the market do not integrate with storage well, and policies and incentives for storage are lacking.

The promise of storage, though, is large, as it can provide a sweeping range of services. There has been a lot of initial focus on electric energy arbitrage (i.e., buying when electricity prices are low and selling when high), but there are also opportunities to provide ancillary services such as frequency regulation and voltage support. As energy storage builds more of an operating history providing ancillary services, it will give regulators and others confidence in the quality and reliability of service and could open more of a market for storage to be built in lieu of transmission.

The best current markets for energy storage involve munis, co-ops, and vertically integrated utilities, as they can use storage systems for multiple functions and monetize all their valuable attributes, including bulk energy services, ancillary services, and transmission and distribution infrastructure services. Ultimately, though, energy storage may do best in markets where there is transparency on price signals.

The growth rate for storage will depend in part on how utilities deal with the challenges to their traditional business model and in part on drivers and enablers such as renewables integration, Federal Energy Regulatory Commission (FERC) orders, and state policy. California, in particular, is poised to break storage wide open with legislation that contemplates a mandate for energy storage (similar to a Renewable Portfolio Standard), the Public Utility Commission's potential inquiry into flexible capacity resources, and the state's self-generation incentive program. In general, energy storage would advance faster if regulators asked utilities to evaluate whether storage is cheaper than building new transmission or new generation.

Carbon Capture, Utilization, and Storage

CCUS used to be viewed as a game-changer, but it seems to have fallen off the radar screen a bit in the United States, though not in China. CCUS and nuclear (which is discussed next) are among the "big and ugly" technologies getting somewhat overlooked. U.S. policy and public opinion are instead focused more on green technology, even though CCUS and nuclear can be supported by some of the same reasoning behind solar, wind, and the like (e.g., low-carbon, increased manufacturing capacity).

The reasons CCUS has stalled have nothing to do with a lack of innovation. In fact, the excessive focus on the need for innovation may be one reason CCUS has made little progress. The U.S. Department of Energy in the mid-2000s had an official target for carbon capture and storage (CCS) costs that was incredibly low, based on the idea that CCS could be so cheap that it could happen without legislation. The target was so low and unachievable that it drove a crazy focus on breakthroughs and R&D, which slowed things down. A couple of large plants are under construction, but generally, very little has happened.

CCUS is not a panacea; there is a lot wrong with it, including high capital expenditures and long-term risks. The general public seems not to like it very much. Environmental groups have generally been hostile to lukewarm, with a few exceptions, and many philanthropic foundations similarly tend not to fund work promoting CCUS – to do so would be to accept that coal might be allowable under some circumstances. Addressing climate change seriously, however, may require finding technologies, perhaps like CCUS, that can be scaled big at affordable cost and without huge land impacts.

Advancing CCUS may require reducing the political headwinds it faces, some of which have been caused by a hard linkage to new coal projects. It may be a different political equation if the technology can be applied to retrofitting existing coal (or gas). Placating fears about carbon dioxide leakage from underground storage sites would help as well, and there are ways to make carbon storage more secure. For instance, when carbon dioxide is dissolved in water, it is denser and wants to go deeper, so stirring the reservoir can accelerate dissolution at a low cost. In addition, it is essential to get some CCUS projects at scale in order to start getting some practical experience. This is part of the reason to pursue projects using carbon capture for enhanced oil recovery, as EOR revenue streams are what currently make some projects viable.

New Nuclear

There are four ways that nuclear might fit into the future power system – some more promising and impactful than others.

First, nuclear might take the path it always has, adding big, expensive, gigawatt-scale plants (which have high energy density and low land use), spurred perhaps by some combination of rising gas prices, a carbon tax, and other measures. There are over 400 nuclear plants in the world, though the United States is down to 100 operating reactors, which account for about 70% of U.S. carbon-free generation. There are about 60-70 new plants under construction – a few of which are being built in vertically integrated states in the U.S. Southeast, and many more of which are being built in China. Approximately 250 new gigawatt-scale plants would be needed globally by 2020 to reduce carbon dioxide emissions by another gigaton annually, but the fastest historical build rate in any country has been only about 4-5 plants a year, so getting anywhere near 250 is going to be difficult.

The second path involves finding a way to build new nuclear plants more cheaply and quickly, and the idea of building small modular reactors is gaining traction. There are four companies in the United States and a few foreign companies with their hats in the ring. There is a hurdle, though, in making the business case for small modular reactors. Possible business models might include either licensing in the United States to sell the reactors overseas or selling the designs to China to manufacture.

The third approach focuses on building systems with much different capabilities – the Generation IV concepts. Generation I involved the early prototypes. Generation II is most of what is online now. Generation III and III+ are evolutionary designs, including modular. Generation IV involves totally different, revolutionary designs (e.g., high-temperature gas-cooled reactors, salt-cooled reactors, sodium-cooled reactors) that are meant to enable cheap, proliferation-resistant, and inherently safe power. China is the test bed and the lead developer for Generation IV projects.

The fourth approach involves hybrid systems that combine nuclear power with other types of energy in a way that optimizes the use of all of them. Examples could include using excess nuclear capacity to produce methanol, extract heavy oil, or boost biomass fuels.

The Process of Innovation

Innovation is sorely needed given the scale of the challenges we face. Between now and mid-century, global population will grow from 7 billion to 9-10 billion, global GDP may almost triple, and there will be enormous increases in global energy demand. At the same time, if we are to reduce global greenhouse gas emissions by at least 50% by 2050, we will need to deploy 1-2 gigawatts (GW) of zero-carbon power every day.

Innovations in technology, business models, and regulatory models are all essential. Such innovations have recently yielded the shale gas bonanza, burgeoning rooftop solar deployment, and other developments. By making clean energy cheaper, innovation can enable economic growth, rising living standards in developing countries, and much more rapid progress in reducing emissions. Governments and utilities each have key roles to play.

The Role of Governments in Innovation

Governments play a vital role in energy innovation, whether via financial support, public procurement, government R&D, assistance in bringing technologies to market, PUC decisions, or well-designed government regulations and policies.

Virtually all energy technologies – wind and shale gas in the United States, pebble bed nuclear reactors and solar panel manufacturing in China, wind turbines in Denmark, etc. – have been developed with substantial government support. Robust, sustained, effectively managed public funding is one of the key mechanisms for accelerating energy innovation.

Sometimes that funding is channeled into government R&D, which can play a role in advancing basic science and helping individual technologies improve. While government can help support the basic science, ideas and individual technologies alone are not enough. Innovation in the 21st century is in many ways about seamlessly integrating constituent technologies to create a better whole – whether a Prius or the grid – and about moving technologies to market. Financial and other forms of government support (e.g., ARPA-E assistance with partnerships and company formation) are needed that not only support R&D but also recognize the critical stages that occur between basic research and commercialization.

It is also important to remember that there is already plenty of technology that can be deployed. In fact, innovation tends to occur where it is closely integrated with deployment and iterative improvements, i.e., learning by doing. DARPA, for instance, is situated in the midst of a larger institution, the Department of Defense, that demands and procures technologies on the cutting edge; there is thus close integration of R&D and deployment. Public procurement is an under-utilized tool in this space – an injection of public funding on the technological demand side instead of the supply side. It may be advisable to couple some government R&D investment policies with policies to procure on the cutting edge of technology.

A problem with many U.S. environmental regulations, especially under the Clean Air Act, is that they are predicated on what is technologically and economically feasible at the time of the regulation. Instead, regulations can be technology forcing, enable competition, or otherwise create conditions that provide incentives for companies to innovate. Ozone transport in the 1990s provides a good example: a NOx reduction standard was set, a cap and trade program was used to implement it, and companies had the incentive to innovate to achieve emission reductions beyond what the target required. It should be noted, though, that there is little evidence that existing market-based pricing policies have induced significant changes in private R&D investments or innovation; such policies generally yield subtle process changes more than big technological innovation.

Still, specific actions by regulators with respect to pricing can facilitate innovation. Good market design should have efficient prices and signals that can promote technologies and practices not yet identified or imagined and can enable the "chance encounters" that can yield clever solutions and breakthroughs. Efficient pricing requires giving people the right signals, and doing so frequently; PJM, for instance, updates prices and dispatch every five minutes for over 10,000 locations. Having the right price signals also means that prices should be as high as marginal cost and that volatility should be whatever it actually is. Lots of technologies could benefit from volatility and scarcity pricing if the right price signals were being sent out instead of being artificially depressed. Pricing would also benefit from greater implementation of things like operating reserve demand curves, which can really make a difference when the system gets tight.

There are times, of course, when regulation can hinder innovation. Smart grid analytics, for instance, sometimes run into the regulatory restraint of cap-ex versus op-ex. If a utility deploys IT developed in the 20th century (e.g., enterprise software behind a firewall), it is treated as a capital expenditure on which the utility can get a return. If, however, the utility uses 21st century IT (e.g., cloud-based infrastructures, software as a service), it is treated as an operating expenditure. This regulatory treatment may deprive ratepayers of innovation.

R&D investments can also sometimes run up against regulators' need to ensure that investments are "prudent" and yield "used and useful" results. Many PUC commissioners may benefit from more education in this area. Utilities should engage regularly with their regulators to get them accustomed to R&D investments and the fact that such investments sometimes yield strikeouts but other times produce grand slams. Utilities should be sure to document their investments and returns so they can demonstrate the significant savings to customers that ultimately result from their aggregate R&D efforts.

There are steps regulators then can take to foster R&D and innovation. For instance, regulators can try to facilitate piloting of new technologies and allow utilities to recover the costs of those pilots. Regulators can follow the example of telecomm in the 1980s, where companies started deploying new technologies, and when a better one came along, the regulators allowed the companies to recover their prior investment and deploy the new technologies going forward without asserting that the prior investments were not prudent.

The Role of Utilities in Innovation

Innovation in the electricity sector has been hindered by capital-intensive technology, an undifferentiated end product, and heavily regulated markets. Utilities also tend to have a strong "if it ain't broke, don't fix it" mentality and invest only a tiny portion of annual revenues in R&D. Disasters like Superstorm Sandy, concerns about climate change, and other factors, however, are starting to convince people within the industry that the system may indeed be broken. In some ways, utilities in regulated markets may be better able to advance R&D and deployment, as those operating in hyper-competitive markets generally have little surplus capital to work with; regulated utilities can usually get at least some rate recovery. There is also a great deal of R&D investment by EPRI, electric co-ops' cooperative research network, and vendors that are seeking to sell to utilities.

Utilities may want to boost and rethink their R&D investments, maintain a steadfast commitment to research, and try to be heavily involved in the process of innovation by, for example, actively collaborating with other utilities, universities, and vendors. Utilities' involvement in innovation could have several targets. Some of the innovation focus may be on generation, whether piloting new baseload plants or gauging the impact on the distribution system of distributed solar resources. Some focus may also be on engaging with customers and giving them the information they need to make choices about their energy use. In addition, there may be opportunities for utilities to explore technology innovation and deployment that helps customers convert from diesel to electric equipment and vehicles. Perhaps most importantly, given all of the developments on the horizon regarding supply, end use, renewables, electric vehicles, and the smart grid, utilities may want to focus on innovations that help them integrate all of these elements and optimize the system.

Resilience, Reliability, & Cybersecurity

Superstorm Sandy and other natural disasters, as well as physical security and cybersecurity threats, have heightened concerns about the ability of the electricity system to prevent, withstand, and recover from emergencies. These concerns carry particular weight in today's world, where the value of electricity to the economy and society is vastly higher that it was even a decade ago.

Natural Disasters & Physical Attacks

Billion dollar weather disasters in the United States have been increasing dramatically since 1980, at a total cost of $1 trillion, and record-breaking storms are now the new normal. These disasters have impacted and will continue to impact all energy providers.

Natural disasters are not the only threats. The electricity system is facing physical attacks, too, such as the sophisticated attack on a PG&E substation in California in April, which featured sniper-range shooting from three angles, fiber optic cables that had been severed to cut lines of communication, and perpetrators that disappeared within 70 seconds of firing the last shot.

While the entire electricity system cannot be built to withstand all extreme events, there is more thought being given now to the resilience of the physical grid itself – such as which materials to use for poles, which systems to put underground, and where trees along power lines need to be trimmed. Some utilities are proposing grid resiliency charges in their rate cases, seeking pre-approval of costs for tree trimming, undergrounding, and feeder replacement. Hardening the system is very expensive, however, so utilities may place particular focus on critical utility assets. For example, utilities may seek to ensure that they have a hardened transmission path to each substation. They may also focus on those areas where the greatest societal and economic costs would fall from long-duration interruptions, such as emergency response services, communications, and transportation. Hardening programs have to be customized to each utility's relevant hazard types and the damages those hazards can cause, such as off-line generation plants, hazardous work zones, inaccessible public transportation, and degraded communications systems. In addition, technological developments like hydrophobic coatings could have a huge impact in protecting electricity system infrastructure.

There are also procedural and planning steps that can be taken to improve the resilience, reliability, and restorative ability of the system, including the following:

- The industry post-Sandy has a process in place for bringing down the walls between regional mutual assistance groups (RMAGs) so that aid resources are aggregated and fairly allocated in the event of an emergency with wide geographic scope. Some RMAGs have also consolidated. Co-ops, too, have in place a range of mutual aid agreements, including with munis and investor-owned utilities.
- More thought is given now to improving supply chain management and to staging resources so that materials can get to customers faster.
- National response event drills are advancing preparation and learning.
- Utilities are getting increasingly involved in weather forecasting.

- In response to changing customer expectations with respect to how long they are willing to be out of power and how frequently they get information updates, utilities are increasingly using social media to communicate – linking to outage maps, relaying what the repair situation and timing may be, etc. – and generally trying to give people the information they need to plan for and manage during outages.
- Utilities are making sure they have strong coordination with relevant state and municipal government crews (e.g., Public Works, Transportation).
- Utilities are arranging to have financial instruments in place that enable them to handle tens of millions of dollars in expenses per day to respond to emergencies.

In addition, building a resilient energy system that minimizes disruption and quickly restores basic services may require the industry to think about how best to move to a smarter, more distributed grid, with advanced sensor technology, advanced forecasting, advanced analytics, and advanced controls. It is incumbent on utilities when seeking regulatory approval of investments in such a grid to make the argument to their regulators that these are investments in system resilience. Advanced metering infrastructure, for instance, enables quicker, more efficient restoration for utilities and other providers. Automatic reclosers, smart feeder switching, islandable microgrids, and strategies such as sectionalizing can enhance redundancy, enable coupling with and decoupling from the system, and generally make the system more dynamically responsive and self-healing. Distribution fault anticipators that can predict where problems will come could be a reliability game-changer.

There are challenges, of course, in building a resilient system. Interoperability standards, for example, are a key area where we still fall short. Regulatory lag is a problem as well, as capital spending to upgrade the system does not always sync well with regulatory cost recovery. The amount of that spending, too, is sometimes determined not by the capital outlays actually needed but rather by the level of rate impact. An entirely separate challenge stems from the fact that half of the nation's linemen – who are responsible for maintaining the infrastructure – are eligible to retire in the next 5-10 years.

Cybersecurity

Cybersecurity is a real challenge for the electric power system. Already, a New York utility had an event last year in which a virus lay dormant in the system for a year, was activated from overseas, and took all customer records, Social Security numbers, and bank accounts. And that was just about customer data, not the reliability of the grid itself. The big concern is the catastrophic event – e.g., someone getting into the energy management system and putting up a mirror to the regional transmission organization that a utility is short or long on capacity, which means the utility would get more or less generation than needed, which could lead to the loss of substations or lines. Such a scenario could lead to power being out for a long time. Extended loss of electricity could result in human suffering, gaps in national security, and severe economic impacts.

The threats a decade ago were from individual hackers experimenting with what they could do. The threat a couple of years ago was more focused on "hacktivists" (e.g., the Anonymous group) making statements. Now there are criminal enterprises and nation states involved – advanced, persistent threats that are growing in sophistication and increasingly going after softer targets like critical infrastructure. Industrial espionage is also a concern.

From 2010 to 2012, there were several cyberattacks by friendly nation-states targeted at the Middle East that were designed to collect information and intelligence or to disrupt the Iranian enrichment program and oil ministry. That was Act 1. Act 2 was the response. In August and September 2012, there were cyberattacks on Saudi Aramco and RasGas, destroying hard drives and computer systems on the business side; 30,000 desktops went down in seconds. Shortly after, about a dozen U.S. banks got attacked with distributed denial of service (DDOS) attacks, and now the financial sector has to wrestle with DDOS attacks more or less weekly. At about the same time in 2012, Telvent got breached. The company, which specializes in IT services for the energy industry, had malicious code inserted into its system on the manufacturing floor, so when others bought the system, the code would be residing undiscovered, ready to open a back door at a later time and let someone else penetrate the control system. All in all, from April 2012 to April 2013, there were over 700 separate reports of indicators of compromise, and many of the indicators came from China. Around 83% of reports were due to email phishing – the human interface. Only 3% involved the electricity sector.

These are just the tip of the iceberg. For one thing, the power system is ubiquitous and increasingly digital. Interconnectedness is usually seen as a real strength of the system – and it still is – but it can also raise risks. As distributed assets and remote cloud-based systems increase, there will be greater need for sophisticated cybersecurity efforts. In addition, there has been exponential growth in threat sophistication and the ready availability of hacker tools.

The strategic goal is to keep malware and cyberattacks infrequent and low-impact. There is defense in depth – in multi-layer protection. The first layer is a foundational set of local and organizational policies and controls (e.g., Critical Infrastructure Protection standards) that help entities figure out how to fight and defend against threats that are well-known and identified. The bulk power system has done a good job of implementing mandatory cyber standards and compliance monitoring requirements. The layer above that involves alerts, notifications, information sharing, and analytics capability, as new threats are exposed and industry has to adapt. Above that, there are high-level public-private partnerships to deal with advanced threat actors. The top layer involves nation-state tools.

The long-term strategy for the system as a whole needs to involve continuous risk assessment, bulk power system cyber standards, active compliance monitoring, active information sharing and analysis, strategic public-private partnerships, technical committees, training and exercises, further insulation of control systems through technology, investment in cyber expertise ("cyber warriors"), and self-assessments using exercises and drills. Individual companies need to focus on the highest risks, rely on best practices (including firewalls and limiting which computers can use flash drives), share information, improve their forensic capacity, conduct tabletop exercises and penetration testing, conduct regular CEO-cyber expert meetings, and exercise their communication response.

On the policy front, there is a question as to whether the federal government should have a more offensive policy focused on using statecraft and other measures to deter nation states from engaging in cyberattacks. One option could be for the U.S. government to make clear that a cyberattack from a foreign state on a U.S. business will be considered an attack on the United States itself. The United States may or may not be good enough right now to be able to issue a credible threat to respond in kind, but it may be time to stop being defensive and become more offensive on cybersecurity.

Lessons from China

The global marketplace is increasingly a source of capital and test beds for technological development. At the same time, mass markets have significant power to bring down energy technology costs. No place embodies these realities more than China.

A few years ago, the talk was about China being on the rise. At this point, the talk is more about lessons that can be learned from China.

China's rise has much to do with scale. It has the largest population in the world. It will have more than 220 cities with populations exceeding 1 million by 2025. The largest infrastructure investment possibly in human history is happening there, accounting for one-fifth of the world's construction industry by 2020. Sometime in the next 5-10 years, China will have the largest economy in the world. It is expected to construct more generation than the entire U.S. fleet in the next 15 years and will have the largest clean tech and nuclear investments in the world. Of course, the scale of this growth has caused equally large problems. For example, China is the world's largest emitter of carbon and the largest generator of rubbish, and it is facing serious air quality and water scarcity problems.

China's Energy Inflection

In the mid-1990s, Chinese leadership switched its view of urbanization, seeing it as a source of economic growth instead of a source of political instability. This led to the largest migration in human history, lots of construction, lots of demand for basic materials, and massive production growth that both accompanied and accelerated consumption. The big increase in heavy industry led to a huge expansion in power generation capacity; China has been adding 90-110 GW each year, mostly coal or hydro. This growth was enabled by incredibly cheap capital for state-owned enterprises, due to financial repression on a massive scale.

Because this growth model consumed a lot of energy but created few jobs, Chinese leadership from 2004-2008 began talking about economic re-balancing and moving toward more labor-intensive light manufacturing and services. Those plans were derailed, however, by the 2008 economic crisis, during which Chinese exports dropped sharply. Leadership instead injected a surge of liquidity into the state-owned banking sector, which kept energy intensity high.

There have been calls for another shot of liquidity now, but so far, leadership has been allowing some short-term pain for structural readjustment. In fact, on June 20, 2013, the SHIBOR overnight interest rate for banks spiked to 13%, signaling that leadership is still planning to force the economy to restructure. This suggests that it will be a hard year ahead in terms of Chinese growth and power demand, and there has already been a sharp decline in industrial electricity demand growth. Historically, when power demand has fallen, it has opened a window for reform of the power sector, so the potential now exists for the most significant reforms to the Chinese power sector in a decade. It remains an open question, though, whether leadership will continue to stick with its current route or go for another liquidity fix, which could lead to continued deceleration of growth.

Assuming power sector reforms go forward, there are competing visions for how China's State Grid, which controls virtually all distribution and transmission, can be reformed. On the one hand, the State Grid's vision involves patching the country together with ultra-high voltage transmission lines, putting coal plants near the mine mouth, and shipping the power to load centers. This approach would have the effect of getting coal out of the cities, thereby improving air quality. The second vision involves breaking up the State Grid into regional grids, allowing more regional control, and revising prices to incentivize distributed generation and demand side management. Which vision prevails will determine China's power mix for the next few decades. The State Grid is very politically powerful, so this will be a big battle that plays out over the next year; it is entirely possible that grid reform will not happen. Apart from the structure, there are also lots of reforms that may happen in terms of end-use pricing.

China is also at something of a transition point on climate issues. For example, seven provinces in China are launching pilot carbon schemes this year with intensity-based targets. China's leaders are concerned about risks to the country's international reputation from being the world's largest greenhouse gas emitter and are sensitive to multilateral criticism. There is also growing concern about the impacts of climate change on China. Still, climate change remains a second-tier motivator in China compared to economic growth, local air quality, and other issues.

Renewables in China

China has gone through three fairly distinct phases on renewables over the past seven years. The first phase was general disinterest, which ended around 2006. The second phase, from about 2006 to 2011 or 2012, involved a surge of investment in renewables. The third phase, which is happening now, is a much more complex one, involving a period of glut.

China has had a massive impact on the global renewables market. Two-thirds of global solar PV manufacturing is on Chinese soil, up from almost zero in 2006. China helped commoditize the market for PV and helped drop the cost of a solar module 75% over four years, though the combination of U.S. and EU tariffs on Chinese solar modules might lead to slightly higher PV costs. About half of wind manufacturing is also now on Chinese soil, though China's export strategy has been much less successful with wind, as there are real questions about quality, financing, and cost once shipped. Lagging intellectual property disputes are also creating problems for Chinese wind companies looking to send product overseas. While China may be the top producer of PV and turbines, the level of innovation is relatively low. The technological innovation occurs elsewhere; China is just where it is most easily scaled up.

For both solar and wind, though, supply is currently much greater than demand. There is massive overcapacity. There are some efforts to use the extra capacity to increase local PV demand in China, but that still does not begin to cover the extent of overcapacity. Renewable energy is less important to China than China is to renewable energy. At the same time, as noted above, the spigot of cheap capital for energy is being turned off. Many wind and PV manufacturing companies in China are going bankrupt. It is an open question how much unfettered consolidation and corporate failure will be allowed – or whether it is too important to local and national party officials to keep these factories running.

Fossil Fuels in China

Even with all the renewables, China is consuming nearly as much coal as the rest of the world combined. The country has a massive fleet of coal-fired power plants, most of which are less than 10-15 years old. China is also suffering from incredibly bad air quality. The government is therefore looking hard at environmental issues and is initiating a number of CCUS projects related to power generation, including projects targeted at enhanced oil recovery and storage in saline aquifers (though China is much more interested in utilization than in storage).

It is very difficult for U.S. utilities to get money for CCUS research today. Engagement in China allows them to stay updated and gain experience with CCUS research and technologies. Under the auspices of the US-China Clean Energy Research Center, American utilities have undertaken studies on the feasibility of applying the post-combustion carbon capture technologies used in Chinese facilities, performed studies analyzing ways to grow algae to absorb carbon dioxide and then find uses for the algae (e.g., biofuels), and initiated agreements to share best practices with Chinese partners concerning integrated gasification combined cycle plants.

As for shale gas, China has only drilled about 60 wells, compared to tens of thousands in the United States. The subsurface in China is a state secret, so there is no ability to share information. The subsurface is also more geologically challenging (and thus costly) than in the United States. In addition, China's two major oil and gas companies, which hold 95% of the relevant acreage, are not eager to develop those resources, as the return from production is low. Reflecting the opposite dynamic as CCUS, Chinese companies are investing in and gaining expertise with shale gas in North America.

As for oil, China is likely to become much more dependent on imports in the years to come, but the country already has a fairly aggressive effort on fuel efficiency standards for light-duty vehicles, is working on heavy-duty vehicles, and has no oil to speak of in its power generation. There may not be much more it can do over the next decade beyond the existing policies. A decade or two after that, though, it will be interesting to see whether all of the new big cities look like Shanghai or like Beijing, which has five times the vehicle penetration of Shanghai.

Nuclear in China

About 12 GW of nuclear power are currently installed in China. China is building 25 new nuclear stations – modifying the designs as they go and bringing the units online faster and cheaper than would be possible in the United States. China has a goal of achieving 70 GW of nuclear energy in 2020, 56 GW of which are already approved; the rest are not allowed to be Generation II reactors. (This may push those reactors to countries like Pakistan and Nigeria, which may operate them even less safely than China.) Post-Fukushima, China also prohibited new nuclear plants next to inland waterways, so all the new plants will be coastal.

U.S. nuclear manufacturing companies are going to China to construct large commercial reactors because they are so much easier to build there than in the United States. As noted earlier, China has become the test bed and the lead developer for Generation IV projects and more broadly for U.S. nuclear energy technologies. Chinese-built Generation IV nuclear projects may be operational by 2017 or 2018 – which will generate the first real data on Generation IV operations and cost. With all this activity, China may well control nuclear energy technology within a decade. On the other hand, the Chinese have joined the World Association of Nuclear Operators (WANO) chapters in the United States because the self-regulation is more rigorous; if the Chinese ever want to commercialize reactors, they will need the U.S. stamp of approval.

Appendices

Agenda

Wednesday, July 3

6:30 – 9:00 PM	**Opening Reception and Dinner**

Thursday, July 4

8:00 – 11:30 AM

SESSION I: ENVISIONING THE FUTURE

Several variables make it difficult to foresee how the electricity sector will change in coming decades. The industry of the future will be shaped in part by external factors, but the visions of industry leaders can also help set the direction of change. Several presentations will introduce a discussion of what might or should happen.

Chair: Phil Sharp, President, Resources for the Future

Innovation – Disintermediation – Vanishing Demand	**Jim Rogers, Chairman** **Duke Energy**
Realizing the Vision of the Smart Grid	**Tom Siebel, CEO** **C3 Energy**
The Shifting Strategic Landscape	**Peter Evans, Director** **Global Strategy Analytics** **General Electric Corporate**

Policy for a Clean Future	**Hal Harvey, CEO Energy Innovation: Policy and Technology, LLC**

Friday, July 5

8:30 AM – Noon

SESSION II: THE PROCESS OF INNOVATION

Innovation can be stimulated in different ways. This session will consider the relative roles of regulation and R&D, the role of government in helping breakthrough technologies achieve success in the market, the role of utilities acting alone or in partnership with others, and the role of electricity prices.

Chair: Bill Dickenson, Energy Practice Leader, Navigant

The Roles of Regulation and R&D	**Ted Nordhaus, Chairman The Breakthrough Institute**
	Mark Brownstein Associate Vice President and Chief Counsel US Climate and Energy Program Environmental Defense Fund
Government as Enabler	**Cheryl Martin, Deputy Director ARPA-E**
The Role of the Utility	**Kim Greene, President and CEO Southern Company Services Southern Company**
The Demand Pull Model	**Bill Hogan, Professor Global Energy Policy Harvard Kennedy School**

1:30 – 5:00 PM

SESSION III: LESSONS FROM CHINA

In part due to the rapid expansion of China's electricity sector, more money is being spent in some areas of research and development than in the United States. Presentations on the energy situation in China and areas of significant investment, some in partnership with U.S. companies, will introduce a discussion of whether the U.S. can benefit from some of the Chinese technological advances.

Chair: Clint Vince, Chair, Energy, Dentons

The Evolving Energy Landscape	**Trevor Houser, Partner** **The Rhodium Group**
Renewables	**Ethan Zindler, Head** **Policy Analysis** **Bloomberg New Energy Finance**
Coal and Carbon Capture	**David Mohler, Vice President** **Emerging Technology, Duke Energy**

6:30 – 9:00 PM	**Forum Reception and Dinner**

Saturday, July 6

8:30 AM – Noon

SESSION IV: RESILIENCE, RELIABILITY AND CYBERSECURITY

Hurricane Sandy and other storms and cybersecurity threats at the utility and grid levels have heightened concern about the ability of the electricity sector to prevent or respond to emergencies. Presentations from people with responsibility in various parts of the system will lead into a broader discussion of the problems and possible solutions.

Chair: Nick Akins, CEO, American Electric Power

Kevin Fitzgerald, Executive VP and General Counsel, Pepco Holdings, Inc.

Michael Hervey, Director, Navigant (former CEO, LIPA)

John Hewa, VP, Research, Engineering, and Technical Services, NRECA

Matt Blizard, Director, Critical Infrastructure Protection, NERC

Sunday, July 7

8:00 – 11:30 AM

SESSION V: POTENTIAL GAME CHANGERS

As Neils Bohr said, "Prediction is very difficult, especially about the future." Unexpectedly cheap and abundant natural gas is the most recent surprising twist for the electricity industry. Speakers will discuss four other areas where some believe a technological breakthrough or faster-than-expected market penetration of existing technologies could similarly upset expectations, leading to a broader discussion of what might be possible and how the industry should prepare.

Chair: Jane Long, California Council on Science and Technology, EDF, UC Berkeley, and the Bipartisan Policy Center

Solar	**Peter Liu, Co-Founder and Managing Director Clean Energy Advantage Partners**
Storage	**Darrell Hayslip, President Narrow Gate Energy, LLC**
CO_2 Capture	**David Keith, Professor Harvard Kennedy School, and President, Carbon Engineering**
New Nuclear	**Todd Allen, Deputy Director Science and Technology Idaho National Laboratory**

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