Energy in a Time of Innovation & Volatility: Moving Towards a Low-Carbon, Distributed, and Resilient Energy System

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THE ASPEN INSTITUTE
ENERGY & ENVIRONMENT
PROGRAM

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TABLE OF CONTENTS

FOREWORD 2

EXECUTIVE SUMMARY 4

EMERGING TRENDS IN THE ENERGY SECTOR 6

CHANGING RATES AND UTILITY BUSINESS MODELS 11

TRANSITIONING TO A LOW-CARBON FUTURE 16

RESILIENCE AND SECURITY 22

APPENDICES

- AGENDA 26
- PARTICIPANTS 29

FOREWORD

This year marks the 40th Anniversary of the Aspen Institute Energy Policy Forum. In 1977 energy policy was, and to some extent still is, largely a derivative of economic, security, and environmental policy. Most energy bills passed by Congress around that time were narrow, but Aspen became a place where larger themes and concepts could be discussed; these discussions helped solidify the concept of "energy policy" per se. During the early years of the Forum, each year's gathering focused on a single specific policy issue but over time the Forum has taken on a broader perspective and now seeks to identify the connectedness among many different, and, often, competing, issues. This year was no exception as participants grappled with a variety of timely issues impacting energy policy including: global energy supply and use trends, continuing challenges to the utility business model, concerns about climate change, fast-evolving resilience and security risks, and disruptive new technologies.

Anne Pramaggiore, President and Chief Executive Officer of ComEd, and Clint Vince, the chair of Dentons' US Energy Practice, co-chaired the Forum. Their extensive knowledge and experience enabled them frame and guide the discussion and elicit useful contributions from the diverse expert participants. The highly qualified speakers listed in the agenda provided a wealth of information and a variety of perspectives, contributing substantially to the overall richness of the dialogue at the Forum.

The Institute acknowledges and thanks our sponsors for their financial support. Most have been participants and supporters for many years. Their generosity and commitment to our work ensures the Forum is able to continue to provide valuable high-level discussion.

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Over the last 40 years, the direct impact of the Forum on policy-making has always been difficult to quantify. However, the true lasting and ultimately more important influence of the Forum has likely been on individuals who attended – and how they have carried what they learned about issues and themselves in Aspen into the broader policy and business arenas. Forum participants gain perspectives, test ideas, participate in thought-provoking discussions, make predictions (often proven wrong), and are inspired to act on key issues. Many of the key learnings and connections have occur outside of the meeting room, with important professional and personal relationships established over meals, during free time, or on hikes. The Aspen Forums have fostered both knowledge and friendships, and they will surely continue to do so for many years to come.

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EXECUTIVE SUMMARY

In the United States and around the world, the energy sector is in a period of volatility, innovation, change, and opportunity. In the oil and gas realm, prices have declined precipitously, with ramifications for global supply, though US shale production has been relatively resilient. Oil demand has generally responded robustly to the low prices, but Chinese demand for oil might peak soon – a development that would have been unimaginable a few years ago. As for the global demand for gas, export potential in the US must contend with the abundance of cheap coal around the world and competitive renewables; small changes in gas prices have huge impacts on how natural gas competes with renewables and coal.

There are many regions of the United States where distributed generation is already at grid parity.

There are also several trends affecting the US power industry in particular, including increasing customer choice and demands, growing pressure to decarbonize, more distributed energy resources (DER), flat demand growth, and accelerating technological innovation. Prices for solar photovoltaics (PV), wind, and battery storage are declining rapidly, while energy efficiency technologies such as LEDs are significantly impacting US load growth. There are many regions of the United States where distributed generation is already at grid parity. Increasing digitization of the grid, analysis of big data, and growth in connected devices is beginning to have a significant impact on energy generation, distribution, and use. An additional trend in the energy sector – but by no means limited to the energy sector – is the apparent breakdown in civic discourse in the country, with debates around policies growing dramatic and personal.

Actors in the US power sector are exploring the potential impacts of these trends on rates and utility business models. Some utilities and planners are trying to figure out how to fully integrate DER into planning and operations – and asses the fit between DER attributes and particular grid locations – without disrupting the provision of safe, reliable, affordable power. Rate design has to focus on integrating the entire suite of DER technologies (not just rooftop solar) in ways that fairly compensate all parties for the value they provide to the grid, while also addressing issues of equity and providing adequate support for grid maintenance and upgrades.

Time-of-use rates and other kinds of price signals can incentivize behavioral change, but technology tools may be needed to automate responses and help shift and reduce energy consumption. Utility business models, meanwhile, may need to (and, in some places, are beginning to) shift, with some functions (e.g., grid construction, maintenance, operation, and planning) remaining regulated utility functions while others are opened to competition. Some utilities are considering a platform model that would have them serving more as network operators enabling interactions among various parties. California, as is often the case, has been at the forefront of "the future", pioneering business models and procurement efforts involving DER, storage, and clean energy.

Climate change is only one of many drivers of the various trends and transformations affecting the energy sector. The list of ways to reduce carbon emissions from energy is fairly short. The options are basically: (1) conservation and energy efficiency; (2) reducing reliance on fossil fuels or substituting them with lower emitting ones; (3) carbon capture, storage, and utilization (CCSU); and (4) zero-carbon energy displacing other dispatch. Currently affordable options include energy efficiency, utility scale PV, and wind, but a range of technologies will likely have to play a role in achieving a low-carbon future, including hydropower, energy storage, nuclear power, power management, and improved efficiencies and CCSU for the existing global fleet of fossil fuel plants. It is important to get both long-term and short-term emission reduction efforts right, but there is no Gantt chart of deep decarbonization steps that considerable could help identify priorities and solutions across timelines. It is also important to recognize that the transformation is not inevitable; policies at all levels of government have played and will continue to play a critical role in driving greenhouse gas reductions, including efforts to advance grid integration, grid infrastructure, and sustainable transport options at a pace and scale that matter.

Developing a modernized, integrated grid capable of delivering (two-way) distribution is equally important from the perspective of resilience and security.

Developing a modernized, integrated grid capable of delivering (two-way) distribution is equally important from the perspective of resilience and security and may produce larger efficiency gains in infrastructure than any single investment. Whether focused on extreme weather events, physical attacks on infrastructure, cyberattacks, or some unforeseeable "black swan" events, security and resilience are of growing concern in the energy sector. Energy companies need to prepare as best they can, working through scenarios, instituting policies to guard against internal and cyber threats, and developing crisis response plans – though efforts may be better spent on boosting system resilience and restoration than on up-front security. Similarly, resilience has to be incorporated into the way the grid as a whole is built and operated, which could include microgrids, storage, fewer big critical substations, greater redundancy and optionality, and reserves of critical equipment such as transformers. This more decentralized, modular way of running the grid means that an event can be more readily isolated, cascading problems can be avoided, and restoration of power to smaller nodes of the grid can occur more quickly. Numerous government standards and voluntary collaboratives have been established to promote grid security and resilience, information sharing, and threat response.

Major takeaways from the 2016 Aspen Institute Energy Policy Forum included the following:

- **The US electricity system is in a period of rapid change, and some utility leaders recognize that modernizing their business models to account for rapidly increasing renewable sources and more distributed generation is key to survival.**
- **Utilities and state commissions are working to finance a common infrastructure, such as transmission and distribution, as more people generate power from home.**
- **Inexpensive natural gas is out-competing coal; solar and on-shore wind are nearing cost parity with large station generators; and nuclear plants in some states are shutting down due to losing economics.**
- **For the US to reach its carbon management and pollution reduction goals, the nation will have to use all options, including: renewables, nuclear, carbon capture and storage for coal and, eventually, gas, energy efficiency, demand response, and both home-scale battery storage, and the 'holy grail', utility scale battery storage.**
- **The biggest near-term uncertainty for the power sector right now could be transportation. If the EV adoption curve is steeper than it's been in the last few years, then demand for electricity may actually go up, instead of the current forecasts calling for flat or slightly decline demand, which has big implications for calibrating generation capacity, investment and retirement.**

EMERGING TRENDS IN THE ENERGY SECTOR

The energy industry is in the midst of a period of volatility, innovation, change, and opportunity. Oil and gas prices have plummeted (though they are starting to rise again), and global geopolitics are in flux given developments in Asia, the Middle East, North America, and elsewhere. Renewable energy technologies, especially with the tax extenders enacted by Congress at the end of 2015, are an important and growing part of the supply chart. Distributed energy resources are an area of increasing interest and activity. Brilliant machines are proliferating, as are big data analytics. Technological innovation and market changes are booming in the energy realm.

GLOBAL OIL PRICES

The United States operates within an interconnected global energy system. That system is in the midst of one of the steepest oil price collapses in history, though the market is starting to adjust. Low prices are doing what low prices do, namely cause supply to fall (despite sharp increases in Iranian production since the lifting of the economic sanctions against the country).

Demand is also responding robustly, with demand growth in 2015 twice the level in 2014, driven mostly by the United States, India, and China. Looking at demand going forward, the oil demand outlook is highly uncertain, affected by variables such as what is happening in OPEC and the emerging markets of China and India. Whereas the talk about China used to be about its unquenchable thirst for oil, discussions now are about when Chinese demand might peak, as the mix of products has shifted, diesel demand has slowed, and the Chinese economy is shifting to a more service-based model. There also seems to be evidence, at least anecdotal, of a sea change in China on the subject of climate change; China appears to be actively pursuing reductions in energy demand and emissions. It might be too soon, though, to suggest that Chinese oil demand will peak any time soon, given the apparent disconnect between aspirational goals in the latest five-year plan and the actual policies being put in place, as well as the internecine conflicts involved in China's pursuit of deep political reforms.

The global oil price collapse has resulted in a $1 trillion cutback on capital expenditures through 2020.

Another consequence of the global oil price collapse has been a dramatic reduction in investment: a $1 trillion capex cutback through 2020. If demand remains robust, it is easy to see prices rebounding sooner than futures curves currently project, setting up the potential for an underinvestment cycle. While some large oil and gas companies are thinking about diversification strategies for capital allocation, and some investment dollars that historically went to oil and gas are now moving towards clean energy, it is not clear that the $1 trillion in capex is not still needed within the oil and gas sector.

In the United States, the oil price collapse hit production somewhat hard, though not as hard as many might have expected. While production is down almost a million barrels a day from its peak last year, US shale has been remarkably resilient due to improvements in productivity and efficiency, high-grading of wells, and squeezing service company costs; not all of those are sustainable over time, meaning higher prices (say, around $75) may be needed for US shale to really perform. Still, with prices back up around $50, rig counts should start rising again soon, and shale will start to stabilize.

The oil price drop overall has been good for the US economy, though not as good as once would have been expected; it boosted US GDP by 0.2 percentage points. Globally, the price drop has had a huge negative effect on the economies of major oil producing countries such as Nigeria and Venezuela, gutting their revenues. (This has had the effect of creating some opportunities for countries to remove oil subsidies.)

The last few years have been unusual in terms of oil price volatility. The geopolitical conflict between Saudi Arabia and Iran has played a big role in the Saudi decision to keep oil prices low. If OPEC countries continue to hold little spare capacity and continue to abdicate the role of market manager which would represent an historic shift. Without some entity trying to control the market booms and busts, there may be increased oil price volatility ahead, with implications for policies and investments.

GLOBAL NATURAL GAS PRICES

The global natural gas market has also seen a dramatic price collapse in the past several years. Market players who used to think about gas prices around $18-20 per MMBtu are now seeing prices under $5. In the face of these prices, US gas production, like US oil production, has been fairly resilient; the natural gas supply curve has become very flat, and the country has an enormous amount of gas it can produce in the $2-3 range.

The United States is ramping up to become one of the largest exporters of natural gas in the world, and the first export of liquefied natural gas (LNG) from the Lower 48 occurred recently. While it will be hard to bring new LNG projects online, the United States should be exporting around 9 bcf per day by the end of the decade with the existing projects and contracts in place. US LNG appears much more likely to go to the European market than the Asian market.

The domestic competitiveness of natural gas as a fuel in the power mix is highly dependent on policy and price. The US Environmental Protection Agency's Clean Power Plan (CPP) was projected to be really good for gas, but when the CPP is combined with the renewable energy tax extenders passed by Congress at the end of 2015, gas is projected to get crushed by wind and solar. Given cheap coal and cheap renewables, the global vision of a golden age of gas is now in question. Small changes (less than $1) in Henry Hub prices have huge impacts on how natural gas competes with renewables and coal; substitution capability is very sensitive, particularly absent additional policies such as carbon pricing. Renewables are increasingly competitive with gas in different regions of the world – and renewables and energy efficiency have no price volatility. On the other hand, it is not clear whether renewables can be balanced without natural gas at the moment, at least not without a far more deterministic way of siting transmission lines where they are needed.

TRENDS IN THE US POWER SECTOR

Several megatrends that are affecting the US power industry and underpinning the industry's transformation will make electricity's next 40 years look very different from the past. These trends include:

1. The power of customer choice and demands – including the rise of "prosumers" and increasing customer interest in controlling usage, reducing costs, and deciding when and what type of power they use. Consumers are increasingly looking for customization, choice, and control. For instance, hundreds of the largest corporations in

the world have publicly announced their commitments to investing in greenhouse gas reductions, sustainability, and renewable energy initiatives, and some major companies are beginning to leave utilities to generate their own clean power or to sign direct power purchase agreements (PPAs) for clean energy.

2. Growing numbers of carbon emission reduction policies and regulations at all levels of government and in many institutions, including the Paris agreement.
3. Shifting power generation sources. For instance, there is a shift occurring from centralized to decentralized; distributed energy resources are growing three times faster than central generation. There is also a shift from conventional to clean. Coal plants in the United States are being decommissioned and replaced with renewables, and in 2016, natural gas, wind, and solar are expected to account for most new additions to generating capacity. Over the next few years, it is expected that there will be a little less new gas and wind and a lot more new solar PV.
4. Delivery of shareholder value through mergers and acquisitions deals, the value of which has quadrupled compared to just a few years ago.
5. Regionalization of energy resources (i.e., states coming together to try to harness the diversity of their resources, especially for renewables).
6. Merging industries, new entrants, and colliding giants. For instance, Tesla is projected to be producing half a million electric cars per year with ranges over 200 miles and at dramatically lower price points; electric vehicles and datacenters could be important sources of new power demand growth.
7. Greater connectivity, including the rise of social networks and growing connections and partnerships among different market players in the industry.
8. An emerging "energy cloud" that is replacing the old, one-way, centralized infrastructure with a more decentralized, two-way, highly intelligent grid architecture.

Looking ahead, there is projected to be flat demand growth, more resources on the customer side, lots of variability in generation, and lower sales from (but still a need for) central station generation.

Underlying a few of these trends is the fact that technology innovation is accelerating, with things becoming digital, automated, cleaner, more distributed, and cheaper. Technology acceleration is perhaps most evident in the solar, wind, and storage areas, where costs are going down and choice is going up. Storage, for instance, is increasingly being considered and deployed for a range of attributes, including resource adequacy, ancillary services for peakers, smoothing output for wind and solar, and reducing grid congestion. Solar PV is also growing quickly, with PV modules 80% cheaper than just five years ago; utility solar costs are now down to around the $40/MWh range. Capacity factors on wind are approaching 50%, and costs are coming down dramatically, to the point that wind is at parity with gas on a levelized cost of energy basis. The range of prices for US wholesale electricity is now being undercut by the average PPA prices of wind and utility-scale solar, even unsubsidized.

Acceleration is not only occurring with those technologies, however. Energy efficiency technologies are significantly impacting US load growth, with the federal efficiency codes, standards, and rules issued since 2000 projected to save 100 quads of energy, equivalent to all US residential energy consumption for four years. Energy efficiency technologies used to advance very slowly, but now some (e.g., LEDs) are getting better much more rapidly, prying open cracks in utility business models. (Thomas Edison sold light, not electricity, which meant that delivering light more efficiently would earn him more money; that model switched over time to selling a commodity instead of a service, which means that efficiency now cuts utility revenues instead of utility costs.) Connected devices enable better demand side efficiency and energy management, bringing overall utilization down. US energy intensity has dropped 56% in 40 years through structural change and technical efficiency – yielding 31 times more savings than the increase from doubling the supply of renewables. These gains are not just from improved technological components, but also from developing integrative designs to optimize whole systems. Buildings now can save vastly more energy than in 2010 with nearly unchanged technologies due to better integrative design. Integrative design, however, is not incorporated into any industry forecasts or official studies, as it is a design method instead of a new technology.

States with high retail prices are already seeing dramatic movements towards DER. There are many regions of the United States where distributed generation is already at grid parity, both for residential and commercial, and 30 GW of distributed generation capacity are expected to be installed annually starting sometime in the next few years. Surveys of the US power industry indicate that the most prevalent DER over the next decade is expected to be solar, while energy storage and demand response are expected to be most beneficial to grid operations, especially as technology is now enabling demand response to respond more like generation (i.e., in real time). In addition, big data can have a significant impact on energy generation, distribution, and the mix of fuels; aggregating big data in an analytical, predictive way, for instance, can make wind farms operate 25% more efficiently, can significantly reduce emissions in ports, and can enable businesses to be both diagnostic and prognostic.

There are many regions of the United States where distributed generation is already at grid parity, both for residential and commercial.

Many in the industry strongly expect the proliferation of DER to transform the US utility sector, though there appears to be an even split between those who think that transformation is already occurring and those who think the forced shift in utility strategies and business models will not happen until 2030. It is projected that trillions of dollars of investment could support this industry transformation, much of which will shift downstream to the retail segment of the value chain. There could also be $1-1.5 trillion in new value investments in digital infrastructure and associated services by 2030.

Some of these trends have played out in other industries before, such as telecom; while the analogy is not perfect, there are some key similarities and lessons to learn. For one thing, technology can move fast; the shift from landlines to dumb wireless to smart phones occurred really quickly – over the space of about 20 years. In addition, the product was redefined in ways largely unforeseen by the incumbents and other players in the industry; fixed voice used to be dominant, but now it is barely part of the telecom value chain. The economics of the business model changed so quickly that many incumbents missed where the value truly was in the chain – with consumers – whereas some new companies were able to come in, focus on customer primacy, and leverage the existing network (that they did not have to pay to build) to provide new services. A further similarity with telecom is the importance of regulation. Technology in telecom did not really see commercialization until regulation opened up the spectrum in the 1980s. Technology and regulation have been equivalent gods in the transformation of the telecom sector, and the same will likely be true in the electricity sector.

There are some key differences, though, between telecom and electricity. For example, in telecom, there was platform-versus-platform competition, with wires competing against wireless, coaxial, fiber optic, and other systems. In the electricity sector, there is still really only one platform: the grid and wires. There are some efforts to create a separate platform focused on distributed generation and storage, but that platform still relies on the existing platform at minimal or no cost. With a single platform, regulation is still necessary.

BREAKDOWN OF CIVIC DISCOURSE

An additional trend in the energy sector – but by no means limited to the energy sector – is the apparent breakdown in civic discourse in the country. Debates around distributed solar and other energy policies in this new era have grown dramatic and personal, and electricity has become among the most political commodities in the United States. The level of personal rancor among activists is growing at both the state and federal levels, with hardball efforts to squelch any dissent against status quo renewables policies (e.g., current net metering policies to promote rooftop solar in states). Efforts to reform policies are portrayed as unpatriotic. Some regulators have been harassed and sued by various dark money groups spinning conspiratorial fantasies, and there have been efforts to smear and intimidate both regulators and judges. Phone lines have been hacked. The phone numbers of regulators' parents and information about the schools attended by regulators' children have been released. Cars have been stolen, trash rifled through, and private investigators hired to pry into regulators' lives. These efforts have led to resignations of some regulators, and some regulators have sought police protection.

Electricity has become among the most political commodities in the United States.

Some regulators are also avoiding using email or leaving recorded messages because they are subject to growing numbers of Freedom of Information Act (FOIA) requests that could allow people to take bits out of context and use them to impugn regulators. Still, some regulators are of the view that there is no choice but to do everything on work email and open everything up to FOIA, however the information gets used.

The country appears to be at a pivot point between big power and decentralized power, between non-fossil energy and fossil energy. In these discussions, there is a troubling willingness of parties to make up facts, adhere to ideologies, and attack anyone who disagrees. Some of these people may be crazy and unbalanced, but they are also on the cutting edge of something real in terms of the fights about the country's (and planet's) energy future.

CHANGING RATES AND UTILITY BUSINESS MODELS

Given the range of trends affecting the US power sector, actors in the industry are exploring the potential impacts on rates and utility business models. Many utilities and regulators are evaluating how to respond to all these changes – to get to clean, lean, reliable, customized, communal, affordable, value-providing, and other traits – while still preserving some of the values and services they currently provide, such as long-term planning, grid optimization, and integration.

UTILITIES AND THE VALUE OF DER

While there are many reasons customers like to have distributed generation, it is hard to imagine many people going totally off-grid anytime soon; essential services will need to depend on the grid for a long time to come. Utilities will have to spend lots of time planning, making smart investments, and distributing intelligence on the grid in order to be able to control, monitor, measure, and procure distributed resources. While utilities are at different levels of maturity when it comes to integrating DER, utilities and planners need to focus on fully integrating DER into planning and operations without disrupting the provision of safe, reliable, affordable power.

Rate design has to focus on integrating DER in ways that fairly compensate all parties for the value they provide to the grid.

The main benefit of distributed systems is that they can be located in areas with the highest avoided costs and the most value to utilities, co-ops, munis, and customers. A common argument is that DER assets benefit utilities by helping to avoid or defer traditional distribution investments. It turns out, though, that the value of DER to distribution is generally small compared to the value to generation, transmission, and society at large. Studies on the value of DER assets to distribution utilities have found that the value depends on how good a fit there is between the attributes of the particular resources and the location on the grid (as well as on how local rules value DER). Most of the potentially deferrable distribution investments are fixed, with very long lead times, but given locational differences, it is hard to identify which DER assets will defer distribution investments. It may be necessary to over-invest in DER in the short-run, as it remains unclear where exactly it will be needed and how exactly it will behave when called upon to defer investment. If the goal is to have DER be an alternative to traditional distribution investments, there are lessons to be learned from the Public Utility Regulatory Policies Act (PURPA), which in its early days had administratively-calculated standard offer prices that anyone could come and take. Market-based measures of the value of DER are preferable.

Rate design has to focus on integrating DER in ways that fairly compensate all parties for the value they provide to the grid, but regulators are dealing with rate designs that are vestiges of the early 20th century. Commissions in several states are evaluating the benefits and costs of distributed solar to try to get the "value of solar" right, but while rate reform conversations across the country end up dominated by the distributed solar piece, the conversations have to be more holistic, exploring how rates can be redesigned so the entire suite of DER technologies can be deployed in combination in ways of greatest value to the grid and to customers. At the same time, there is a need for rates that support seamless grid upgrades without impacting reliability, particularly given that utility infrastructure has to become more liquid and dynamic at the same time it becomes more hardened, resilient, and reliable.

Bidirectional value tariffs could be a way to move forward, with utilities and customers paying each other the fair value of the services exchanged; that kind of tariff can scale indefinitely without breaking. There is always a question, though, about which values get factored into the equation. Potential costs and values include the risks of intermittency, the costs of infrastructure build-out, storage costs, the locational values of DER (e.g., whether on a congested circuit or not), dispatchability, the resources that DER assets are displacing, and many more. There could be special case compensation for certain DER assets that specifically defer utility fixed-cost investments, such as forward procurements. There should be a broad and inclusive set of values considered.

In a world with much greater penetration of distributed generation, smart thermostats, smart appliances, battery storage, and the like, utility customers could be needing much less power off the grid. Customers are figuring out that they can use electrons more productively, make their own, or sell them to each other – raising questions about how rate structures can ensure the grid continues to get the investment it needs (for backup, if nothing else). Efforts to tax solar PV and other DER installations can annoy customers and accelerate departure from the grid, but utilities need to be able to recover investments for utility functions at the distribution level. Cost of service has to be fairly apportioned, and more accurate price signals have to be sent. Work needs to be done to assess the feasibility of a three-part rate design for customers with on-site DER, consisting of a customer charge, an energy usage charge, and a demand charge. The energy charge will continue to be the most elastic of the charges for consumers, but it is unlikely that it will be able to bear all the fixed costs utilities have, which means a lot will get put into the demand charge. It is unclear if that approach works over time as fixed costs rise and energy charges fall, but having a large demand charge would certainly send signals to consumers. At the same time, utility managers tend to focus on the need for price to exceed cost, but value also has to exceed price. If competitors provide superior value propositions, it does not matter if a utility can profitably sell what consumers are no longer buying. Utilities need to sell customers what they want before someone else does.

Rates involving DER assets and utility cost recovery can raise some thorny equity issues. The most common debate is whether there are regressive social costs involved in policies promoting rooftop solar, namely whether generally poorer non-solar adopters are subsidizing generally wealthier solar adopters. The issues can also go deeper. For instance, factoring in locational value when considering the value of DER makes sense, but if a local distribution system is constrained because wealthy residents there bought expensive electric vehicles, it would make it more valuable to install rooftop solar on that local system – which again reinforces the narrative about poorer non-participants subsidizing wealthier participants.

TECHNOLOGY AND RATES

Rate design and price signals can incentivize behavioral change. Time-of-use rates and demand charges, for instance, could send price signals that reduce peak demand. Technology tools, however, may be essential to helping people flatten their bills, shift peak consumption, and bring energy consumption down.

Utilities that have real-time pricing as an option generally are getting very little uptake, in part because many people do not know about it. Currently, about 40% of US households have access to time-of-use rates, but only about 4% are actually on such rates (mostly in Arizona). It is possible that a better approach would be to make real-time pricing the default, while the current flat rates could be the opt-in choice. (Big data may allow companies to better understand the profiles of different consumer classes and determine whether a mandatory or opt-in approach would be preferable.) In some markets, hourly real-time pricing would immediately lower many customers' bills, with or without energy management. Even that approach may have limited success, though. Ontario introduced mandatory time-of-use rates for all residential customers years ago, but without tools to really enable customers to makes sense of and respond to these rates, the overall consumption reduction and shifting of peak have been rather small.

If these are the types of rates and price signals that consumers will be receiving, then it is important to think about how to roll out tools to better enable consumers – especially older and low-income consumers – to shift behavior.

Many consumers will not be using the latest technologies; there are still many utility customers that want to bring cash to a service center to pay bills, and utilities have to serve them too.

Technologies such as smart thermostats can get people's attention. Technology in homes can also automatically reduce loads (with efficiency) and shift peaks around (with demand response), all in response to rate schedules and while providing feedback on apps and devices. Technology can actually respond better than people sometimes; many customers do not know what they pay per kWh and may have only a general understanding of what their monthly electric bill is, but computers can respond to small changes in price signals that humans would either be unaware of or would ignore. These kinds of technologies can pull all of the complexity of energy and time-of-use rates into the background, helping customers save and get engaged. The result could be improved reliability (e.g., through targeted demand response programs), reduced energy usage, and enhanced affordability.

These technological tools do not necessarily have to be limited to new equipment purchases; they can be deployed in retrofits as well. For instance, there are developers and companies working on easy, quick-install retrofits for existing pool pumps and water heaters to allow them to respond to demand response signals from smart thermostats. As developers continue to engage with "smart home" platforms, the opportunities in the retrofit space should continue to grow. On the other hand, given the huge stock of existing homes, buildings, and equipment, it seems like a lot of the smart home and DER developments are really just playing at the margins.

The pace of change in technologies and consumer demand does not fit well with current rate-setting processes.

The pace of change in technologies and consumer demand does not fit well with current rate-setting processes. New entrants in the sector that come from a software background are building new products in two-week sprints, presenting a challenging juxtaposition with the pace of regulatory processes. In a general rate case, utilities and regulators are supposed to predict the next three years out, despite being in the midst of rapid change. Some rate issues are locked up in law, which is a terrible place to establish rates because it can be so hard to change. With long lead times and an inability to test ideas, the market may have shifted by the time technologies and rates actually make it through the process. There is a need for a regulatory model that enables greater flexibility and more rapid iteration – coming up with a hypothesis, testing it, gathering customer and market data, learning from that data, and making adjustments. While there is a need for methods that enable doing more, faster, it is essential to have measured expectations; utilities generally cannot do things quickly.

NEW UTILITY BUSINESS MODELS

The utility business can be divided into four basic layers of functionality: (1) building and maintaining the physical infrastructure of the grid; (2) operating and planning that infrastructure; (3) transacting in the energy commodity space; and (4) transacting in other types of products and services. There are open questions as to which layers utilities should operate in going forward, whether other market participants could play more strongly in some elements than others, whether some layers should or could be bundled, and how such a network could scale geographically given the regulatory constraints on utilities. It may be that the first two layers stay regulated as a monopoly, to avoid recreating infrastructure and to ensure there is still one entity ensuring local reliability, universal access, and backstop power. It may be that the latter two layers are where competitive businesses (perhaps in addition to utilities) could engage. There will not be one pathway forward to "Utility 2.0", given that there are around 1,700 electric distribution utilities in the country; there will be lots of variations depending on local conditions.

As long as the main utility business model is still to put steel in the ground and earn a regulated rate of return on it, the "transformation" will stay at the margins. Given current trends, though, some utilities are considering a model that would have them serving more as network orchestraters to enable interactions among various parties. In the 20th century, the pipeline model was the dominant business architecture – making a product and sending it through a distribution pipeline to customers. The model emerging in the 21st century is more of a platform model, which is more interaction-focused than product-focused, with growth following consumer uses rather than commodity usage. Utilities can be like the roads everyone drives on – they can be the way entrepreneurs get electricity and services to consumers. This model is more of an ecosystem or network design that has control and value more dispersed among many actors. Energy may be a valuable product, but it also may be that the true value lies elsewhere in the network. There are questions, therefore, about which platforms make sense, where value pockets actually are, and which entities will capture that value.

Different actors in the electricity space bring different strengths and weaknesses to bear. Utilities bring understanding of local communities and legitimacy, and they have the mindset and legal structure to optimize the system for the most number of people. They have not, however, gotten into data analytics as much as they need to. On the other hand, the pace of transformation is set not by the incumbents but by the insurgents, who are not inhibited by incumbent business models, legacy infrastructure, and the like. Market actors innovate more quickly, can customize for individual customers more effectively, and sometimes can avoid the regulatory hurdles present in every state. Market actors, however, tend to have little legitimacy or name recognition among customers. Utilities could play a role in making sure the companies doing the innovation have credibility – akin to having the AAA symbol on the side of a tow truck.

The model emerging in the 21st century is more of a platform model, which is more interaction-focused than product-focused, with growth following consumer uses rather than commodity usage.

A new business model has to continue to ensure affordable, reliable, safe, and clean power; the social compact still matters. Electricity is already cheap in most places, already reliable, and already getting cleaner. There is some question as to whether reliability is as essential going forward. In telecom, people are now paying far more for much worse call reliability, due to the other services being provided. It is conceivable that people might be willing to pay more for less reliable electricity if there are other valuable services involved; some entities and some regions might be more willing to have occasional outages than others. Still, there is a risk that accepting variable reliability could be a slippery slope to providing bad service, or at least bad service to poorer people.

As already noted, technology, rates, and regulators could have significant impacts on the feasibility of new utility business models. There is a need for policies or metrics that allow utilities to explore new areas and earn a return; it is hard to think of another portfolio manager that does not make money off the portfolio. It is possible the utility model may need to change to be more like mutual funds, where managers collect different fees for different levels of risk. Performance-based ratemaking, for example, is a more results-based model allowing for higher return on equity if the utility's results justify it (and presumably lower returns if the utility underperforms). Regulators in many places are seen as stumbling blocks, hindering the ability of utilities to drive innovation and play in some of the new spaces that are opening. Investors, too, can be stumbling blocks; some utilities have recently tried to embrace the vision of an integrated system that operates in a very different way, but their investors have pulled them back from pursuing new business models.

Experiences in California and the West

California tends to lead in many areas involving DER, clean energy, and utility business models. What California is doing today is often "the future" for others.

The fuel mix in California has changed over the years. The transition from coal to natural gas occurred long ago, and coal plants were essentially banished in 2006. Nuclear power has been diminishing as a percentage of the fuel mix. Natural gas is the new coal in California, and the state is now moving to shrink the natural gas part of the pie and replace it with renewables, in part to meet the state's renewables target of 50%. The focus on renewables, in turn, has shifted to "preferred" resources (smaller scale renewables, energy efficiency, demand response, and energy storage) and distributed resources.

California is going through a Distribution Resources Plan proceeding to facilitate the widespread use of localized, distributed resources. Some utilities in the state are increasingly relying on preferred resources to fill any system needs and are beginning to pilot preferred resources in areas where demand is growing to determine whether such resources can deliver what is needed when it is needed. The goal is to displace distribution upgrades with preferred resources, relying on competitive markets. Managing such a distributed grid requires capabilities to predict, monitor, control, and optimize distributed resources.

The pace of change can be accelerated by utility procurement processes, and some California utilities are pursuing procurement efforts tied to energy storage, partly in response to the state's goal of achieving 1300 MW of storage. For example, there is a multi-year PPA in place with private market actors for behind-the-meter storage that can be dispatched hundreds of hours per year for up to four hours at a time. This is demand response on steroids, functioning as a virtual power plant in a specific area of the grid. The storage customers are all on a specific set of circuits tied into a single substation, enabling a coordinated load drop for the substation as needed; the buildings' systems are operated as an integrated fleet. Business innovation has to keep up with technological innovation, and storage requires tapping into many different value streams – such as utility dispatch and customer energy service – to pencil out. Because of storage's many potential attributes, figuring out the business model and the viability of the technology – in California or elsewhere – really comes down to deciding which problems storage is being deployed to try to solve.

Storage could be one (but not the only) potential solution to California's "duck curve" challenge – an abundance of solar power during the middle of the day that then drops off just as peak load is starting. Natural gas generation in California is currently hurting when there is solar in the system and then has to ramp very quickly and steeply later in the day when the solar resources slow and cease production. (In some places, the steepest ramp would not actually be meaningfully different from what already has to happen due to weather changes; high penetration of solar does not necessarily make the ramp steeper, but it does make the steepness happen more often.) Demand response and energy efficiency can play a role in reducing the peak load, but they cannot address what to do with the over-generation of solar during the middle of the day; there has to be a place to put that power. Storage is one possible depository, whether, in batteries, electric vehicles, or elsewhere.

Regionalization is another possible answer to California's over-generation issue. There are seven Regional Transmission Organizations (RTOs) in the United States, which, among other things, help utilities that want to maximize their renewables production to have real-time balancing. Apart from the California Independent System Operator (ISO), there is a big blank space on the map of the West when it comes to RTOs. West of the Rockies, there are 38 separate balancing authorities, all of which have to have their own reserves, providing much less flexibility. These balkanized authorities generally work in an hour-ahead market (as opposed to a more real-time five minute market), and it is hard to trade wind and solar on an hourly basis. However, there has been an energy imbalance market going in the West since November 2014 that involves the California ISO and a few Western utilities. The energy imbalance market creates a real-time market where low-cost resources (usually wind and solar) can bid into the market and win; renewables are now one of the key low-cost options (undercutting the myth of expensive renewables). The market appears to be good for California and its huge amount of excess solar power. The larger the footprint, the better the opportunity to access renewables, but efforts to form a true Western grid – a Western RTO – face some challenging politics and governance issues.

TRANSITIONING TO A LOW-CARBON FUTURE

The issue of climate change is fundamentally shaping energy issues. It will continue to do so, across technologies, sectors, and policies.

REDUCING CARBON EMISSIONS

In figuring out how to reduce carbon emissions into the future, there are many things that are unknown, such as future power demand, the sense of climate urgency, the rate of innovation, or what utility structures will look like. Still, there are many things that will likely be needed, and if action is not taken on them, climate targets will not be achieved.

While many discussions about reducing emissions focus on the power sector, it is not possible to hit climate goals without working in other sectors too, including industrial, residential heating, shipping, carbon removal, and many others. The United States currently consumes about 100 quads of energy – about one-third for power, one-third for industry, and one-third for transportation. The list of ways to reduce carbon emissions from energy is fairly short. The options are basically: (1) conservation and energy efficiency; (2) shutting down fossil fuel plants; (3) carbon capture and storage (CCS); and (4) zero-carbon energy displacing other dispatch. For instance, emissions from petroleum use (mostly in transportation) can really only be addressed by improving efficiency or by displacing it with something else, though displacing petroleum with electricity increases power demand. Industry's options for reducing emissions, in turn, are mainly efficiency and CCS.

While many discussions about reducing emissions focus on the power sector, it is not possible to hit climate goals without working in other sectors too.

Most electricity generation still comes from coal, gas, nuclear, and hydro. The power sector reduced carbon emissions 20% from 2005 to 2015, and in 2016, the power sector in the United States had fewer emissions than the transport sector. Still, there is much more to do, and a range of technologies can play a role.

Currently cheap options include energy efficiency, utility PV, and wind. Costs have been going down rapidly for onshore wind and PV, though it is unclear whether they are or are not starting to flatten out. Getting wind and solar PV to be incredibly cheap – around 3 cents per kWh for wind, under $1 per watt for solar – will be key for a clean energy transformation, and that may happen within a decade. Solar thermal and offshore wind are both still very expensive. Hydropower is incredibly important and can be expanded. Further digital transformation of energy (e.g., further use of big data) could also play an important role. In addition, affordable energy storage could be the crown jewel that transforms the industry.

Nuclear power is a huge percentage of America's current carbon-free power, but plants have begun closing, which likely will have an adverse effect on emissions. It is possible, though, that closing some old nuclear plants (e.g., the ones in the top quartile of operating cost) and reinvesting the opex money into far cheaper renewables and energy efficiency could have the result of saving even more carbon emissions than keeping the nuclear plants running. In the future, small modular reactors may play a role.

Fossil fuels cannot be ignored either. New, state-of-the-art combined cycle gas plants are flexible, efficient (efficiencies upwards of 60%), and inexpensive; there is remarkable under-utilized potential to upgrade existing combined cycle plants to yield huge efficiency increases. (There can also be good partnerships between renewables and gas, as combined cycle gas plants can ramp quickly.) It is similarly vital to upgrade the existing installed coal base globally. While coal retirements are happening in the developed world, the affordability of coal is still important in the developing world, and most forecasts project a sizable portion of generation in the world will be from coal for years to come, much of it in countries such as India and China. The average efficiency of coal plants is around 36%; each one point improvement to the installed base is the equivalent of 250 million tons per year of carbon reductions – and technology can bring about five points in efficiency improvements. Affordable carbon capture, storage, and utilization for gas and coal could also be essential, even if there is never another coal plant built in the United States. The clean fossil fuel side of the story has not really gotten out. The "keep it in the ground" movement has a message that makes sense to some ; if climate change is a true threat, then we have to keep a lot of fossil fuels in the ground. There has not been a clearly articulated message that includes natural gas, improved efficiencies, and what to do about the existing installed base of fossil fuel plants.

Further research and development will be critical; while a lot of current R&D is occurring, it is at the scale of megawatts, which are cute, but gigawatts and terawatts are necessary.

The issues are less about cost than about technology choices and the rules in place in various systems; solutions that are good in one market may make less sense in another. The pace of innovation also matters, which presents a challenge for technologies such as nuclear power and CCS, where the pace of innovation is much slower. Technology advancements can hasten the arrival of a cleaner future. Further research and development will be critical; while a lot of current R&D is occurring, it is at the scale of megawatts, which are cute, but gigawatts and terawatts are necessary. Some progress is happening here and there, but the scale is small, and the pace is slow.

It is important to get both long-term and short-term emission reduction efforts right. A Gantt chart of decarbonization steps could help identify priorities across timelines, but there is no such chart for deep decarbonization, analyzing what the robust solutions are, how fast they have to be developed and deployed, what R&D is needed, where choke points are in the chain (e.g., transmission build-out, lack of an educated workforce), and so on. Given the pace of innovation and long-term climate goals, it is unclear how the durability, duration, or degree of capitalization of an investment should be taken into account in the kind of system that is designed, so as to be responsive to the pace of technological innovation and avoid unknowingly locking in technologies that are higher-emitting. Depreciation signals or other approaches may be needed to avoid locking in long-term investments that are out of sync while still encouraging early investments in long-term solutions.

The transformation to a low-carbon energy system might be costly, though electricity prices are low enough now that they can absorb some incremental costs tied to moving faster to urgently address climate change. On the other hand, it is also possible that achieving a 2°C target or a 1.5°C target, including carbon removal by natural systems (e.g., farming, forestry), might be doable at strongly negative cost – in other words, at significant cost savings – which could change the climate conversation from one about cost, burden, and sacrifice to one about profit, jobs, and competitive advantage.

What the transformation probably will not be, however, is easy. While the transformation may look smooth and inevitable from a macro standpoint, companies living with current technologies have to figure out how to accomplish the transition in pieces. Many companies are not willing or able to invest in the new technologies of the transition, instead trying to get the money possible out of the technologies already in place. Getting the various technology pieces to play together, dealing with stranded cost issues, and other similar challenges will make the transition chaotic.

ROLE OF POLICY

Technological innovation can in some instances quickly move beyond policy and regulation. Policy, however, still plays a critical role.

Some believe that clean energy will win even absent government intervention, but that is not necessarily the case. The trend towards "clean" is often billed as inevitable, but utilities continue to seek subsidies to maintain inefficient, uneconomic, dirty fossil fuel plants. In addition, during the Carter Administration, there were similar conversations about the inevitability of a move to energy efficiency and renewable energy, yet momentum ceased when President Reagan came in and adjusted the incentives, systems, and markets. Policies matter. That, in fact, is part of the rationale for the EPA's Clean Power Plan, which is based on the best system of emission reduction that currently exists; if implemented, the CPP will serve, at minimum, as an anti-backsliding policy.

Policies already in place at all levels of government have been some of the principal drivers of greenhouse gas reductions in the United States.

Policies already in place at all levels of government have been some of the principal drivers of greenhouse gas reductions in the United States. In 2005, the Energy Information Administration estimated that US greenhouse gas emissions would rise substantially by 2014, but they actually dropped significantly instead. Many reductions came from the power sector, with a push from a range of policies, including the Investment Tax Credit (ITC), the Production Tax Credit (PTC), state Renewable Portfolio Standards, and other state and regulatory policies (in addition to cheap natural gas, the recession, pollution control requirements, and other factors).

Still, lots of federal and state policies ostensibly aimed at climate change veer slightly off target. Federal ITCs and PTCs are for renewables, not zero-carbon energy; they exclude nuclear or CCS. State policies such as net metering similarly focus on renewables, as do state renewable energy requirements (as opposed to low- or zero-carbon portfolio standards). There is no federal Clean Energy Portfolio standard. There is a federal renewable fuels standard, but no low-carbon fuels standards (except in California). Even in leading states such as California, most policies designed to reduce carbon emissions do not actually measure carbon reductions, instead tracking metrics such as energy savings. Many of these policies can be (but often are not) analyzed in terms of carbon tax equivalency, to at least provide a means for comparison and consistent measurement.

The big question really is what the effective urgency of climate change is in the policy arena. It is nearly certain that humanity will not hit the 1.5°C target and probably will not hit the 2°C target either, but people are not acting as if the climate challenge is urgent. Americans also appear to have decided as a country that they hate spending money on things, but the United States will have to spend money to achieve deep decarbonization. It is possible that climate impacts could change the sense of urgency; with the heat index in Iran recently reaching 165°F heat index, the Zika virus spreading, huge fires in Canada, a massive drought in California, and other impacts, humanity is already beginning to experience what Al Gore refers to as a family hike through the Book of Revelations.

US polices are not the only ones that matter, even in North America. At the same time that Europe is falling apart (i.e., Brexit), North America is moving towards greater integration, particularly with regard to energy and environmental policy. The "Three Amigos" summit in June 2016 with the leaders of Canada, the United States, and Mexico featured joint announcements to coordinate energy policy, including some ambitious clean energy and methane reduction targets.

Developments in other parts of the world will have a tremendous impact on the entire electric power industry too, as has already occurred with China and the massive reduction in the costs of solar PV. China can be more resolute and single-minded about transformation than is possible in the United States. China is leading the world in solar panel production and wind turbine production, building several nuclear plants, and selling energy technology all over the world; it sees its transformation and leadership as imperative not just for its energy policy but also for its foreign policy. India, meanwhile, has done remarkable work using competitive bids to make renewable energy competitive, and there is over a terawatt of energy efficiency India has not even analyzed yet; on the other hand, India is currently planning to build even more new coal capacity than new solar capacity. Globally, policies to bring electricity to those who currently lack access create exciting opportunities for technological leapfrogging.

Energy efficiency and renewable energy are overwhelmingly popular regardless of political party; they are trans-ideologically attractive if the focus is on outcomes instead of motives.

Amidst this domestic and global swirl of policies aimed – directly or indirectly – at reducing carbon emissions, companies are seeking policy clarity to assure potential investors of returns and open more capital for investment. Clarity of policy does not necessarily mean that it never changes; policies need to provide broad clarity while enabling flexibility. There is a need for policy durability given the scale of investment that has to occur, as well as a need for policy flexibility given the pace of innovation. A carbon tax or similar policy would provide a strong degree of clarity.

Energy efficiency and renewable energy are overwhelmingly popular regardless of political party; they are trans-ideologically attractive if the focus is on outcomes instead of motives. This means that politicians of many stripes, if they like any of the many outcomes that efficiency and renewables create, can support the transition to a clean energy future; they do not have to like every outcome or agree on which is most important. On the other hand, the deployment of technologies is about who gets paid, which ends up being deeply political. It is therefore very important to give policymakers confidence in technologies by bringing them into places where the technology is already in place, helping them touch, see, and feel (either in a physical or virtual space) how these technologies really work.

GRID INTEGRATION FOR A LOW-CARBON FUTURE

Technology makes policy possible. Policy makes finance possible. Finance drives the technology push. It is a virtuous cycle, and innovation happens in all of these areas. Developing, supporting, and financing more technologies and devices, however, only goes so far. There is a need to deploy widgets in an integrated way and at a pace and scale that matter. Grid integration and infrastructure are vital to a low-carbon future.

It is often said that only coal, gas, and nuclear power can keep the lights on 24/7 because they are not variable, but variable does not mean unpredictable. It is possible, for instance, to very accurately forecast the output of wind farms. In addition, all generators go offline sometimes, and one purpose of the grid is to allow for working plants to backup offline plants. In the same way, grids can handle forecastable variations of solar and wind power with other kinds of renewables or with renewables in other places, enabling a portfolio of wholly renewable resources. Energy efficiency can reduce peak loads, renewables can be installed, significant demand can be compressed into solar peak times, and extra renewable power can be put into storage – including air conditioners and electric vehicles – and recovered when needed. Grids can be run the way a conductor leads a symphony orchestra; no instrument plays all the time, but the ensemble continually produces beautiful music. Some believe that such a system could provide 100% renewable power every hour of the year, though others would argue that uneconomic choices would have to be made to realize that goal.

It may be challenging (or impossible) to get to a clean energy economy without remote clean energy resources being connected to the grid by wires, but it is very hard to build transmission lines, which could limit the ability of a wider geographic area of renewables to mitigate renewables' variability. It takes several years to build a transmission line – far longer than it takes to put new generation in place – which means it is necessary to anticipate with transmission capacity where clean energy generation will be. On the other hand, higher wind towers and better rotors can make wind cost-effective in every state, and solar is already rapidly heading that way, which means the notion that it is imperative to do solar in the desert and wind in the high plains and then put wires everywhere may no longer be economically justified. The top quality resources far away from load have about the same delivered price as middling resources closer to load centers, so there may not be a need for quite as much transmission as is commonly believed. It could be desirable to have transmission more explicitly compete with other ways of accomplishing the same ends.

Grids can be run the way a conductor leads a symphony orchestra; no instrument plays all the time, but the ensemble continually produces beautiful music.

Grid integration is not just theoretical. It is already practiced in Europe, where a few countries are meeting sizable portions of their load from renewables, with superior reliability and with no bulk storage. (Batteries have a lot of benefits, especially behind the meter, but bulk storage is not a prerequisite for a renewable energy future; there are many other ways to make the grid more flexible.) Without a centralized electric system like some European countries, though, pursuing integration in the United States can be daunting in light of the 1,700 electric distribution utilities, 50 states (plus DC), and numerous agencies in the US constitutional democracy. US political leadership is also all over the map. Getting to truly huge levels of renewables penetration may require a whole new regime and continued development of grid modernization technology and infrastructure.

A modernized grid should be affordable, resilient, reliable, flexible, secure, and sustainable simultaneously, unlike many current demonstration projects that make tradeoffs among the attributes (e.g., more resilience but higher costs). Achieving such a grid within the next 5-10 years requires different areas of foundational R&D. One involves devices and integrated systems, looking at experiments that illustrate what the typical needs are of a connected device (whether a PV panel, inverter, or EV), both individually and together as systems. A second area involves sensing and measurement; there are not currently sensors across the grid enabling knowledge of the state of the grid at any given moment, and without an ability to know the state of the grid, much less make a forecast about it, it is impossible to tell devices what will be needed from them in the near future (e.g., when the wind dies down in three hours). A third area involves system operations and control, to enable coordination of systems from the level of the grid down to the level of a building; there is research into creating a new open-source platform for advanced distribution management that spans multiple scales. A fourth area involves multi-scale planning and design tools. A fifth involves security and resilience, including cybersecurity approaches for renewables, DER, and smart inverters. A sixth focuses on institutional support, including development of new tools to support distribution system decision making. All these R&D areas can feed into regional demonstration projects to accelerate the transition from R&D outcomes to widespread deployment at scale.

Scale is vital. Most current integration work tends to focus on small units of society (e.g., campuses, industrial parks, parts of communities), trying to optimize the energy system within those units. There is good reason for this; when done at small enough scale, there is no need for a lot of institutions to be involved. Work at this scale, however, is not nearly enough. There is a need to rapidly scale up to at least the city-level electric system and to go beyond the electric grid to encompass thermal energy, fuel supplies, water, wastewater, and other systems. Inside that nexus of several domains is the secret to real acceleration towards a low-carbon future.

TRANSITIONING TO SUSTAINABLE TRANSPORT

One key domain involved in a low-carbon future is transport. Close to 100 million vehicles are produced worldwide, and they have long lives (around 10-20 years), which means turning over the existing fleet of vehicles in favor of newer, cleaner vehicles is a huge task.

For EV success, the fundamental factors appear to be usable range (around 200 miles for US consumers), quick recharging, high performance (e.g., acceleration, handling), high levels of safety, and consumer appeal.

The sustainable transport focus in the United States right now tends to center on electric vehicles (EVs). Some insurgent companies are trying to create enough of a market for electric vehicles that incumbents will see the opportunity and move strongly into the space, and efforts are gaining some traction. The strong demand for Tesla's new Model 3 – more than 300,000 advance orders within a month, all without the car ever being seen – gives the lie to long-standing critiques from automakers that no one wants EVs. The Volkswagen emissions scandal and the company's subsequent responses mean that perhaps the most important automobile manufacturer globally will be making meaningful investments in EVs, which could tip the market. China's governmental push for EVs (in response to the intense air pollution) could also be catalytic for EV development and adoption. Similarly, countries such as India and Germany have recently decided to explore having 100% EVs by 2030.

Still, deep EV penetration and tipping points could take longer than many would prefer. Product cycles are long, on the order of 5-7 years, and many manufacturers have not even started yet. California might achieve its goal of 15% by 2025, but the percentage will be lower nationally, though the curve will rise dramatically once penetration reaches around 5-7%. Global EV sales are already growing 60% per year, and it is projected that EVs could save 2 million barrels of oil a day within the next 7-9 years. That savings figure does not even consider other ways of accelerating EVs such as feebates, ultra-lighting, monetizing EVs as grid resources, or sharable and autonomous mobility service models that advantage electric traction.

For EV success, the fundamental factors appear to be usable range (around 200 miles for US consumers), quick recharging, high performance (e.g., acceleration, handling), high levels of safety, and consumer appeal. Some EVs have started in the market with high price points and low volumes, with iteration and economies of scale enabling low prices and high volumes over time. Incentives and subsidies are currently very important in the EV space, though some incentives are better than others. More important than developing new policies might be removing the regulatory barriers to EVs that currently exist, such as the prohibition against selling vehicles directly to consumers (as opposed to through dealers); sometimes examining existing systems and taking regulations off the books that inhibit insurgents can be just as important as creating new incentives and systems.

There are other opportunities to get sustainability gains from electrification of transport as well. Freight and trains, for instance, are an under-invested opportunity to pursue sustainable transport in the United States, as electric trains are very efficient and get trucks off the road (which has a range of benefits). Government funding, however, tends to go towards roads instead of rails.

RESILIENCE AND SECURITY

Weather is growing more turbulent, with everything from super storms to water scarcity. At the same time, there are more failed and failing states, nefarious non-state actors, and cyberattacks than there have ever been. Issues concerning cybersecurity, physical security, and resilience are thus of growing concern and seriousness in the energy sector.

BLACK SWAN SCENARIOS

"Black swan" events are unpredictable, very low percentage occurrences that have huge impact; in other words, they are "impossible" scenarios that actually happen. Black swan events can spur paradigm shifts, forcing people to think about threats they never had to think about before.

Black swan events, by definition, are very unpredictable and hard to imagine, which means they are generally hard to thwart. There are an infinite number of scenarios that companies could dream up, and it is not possible to prioritize them, but devising and developing responses to all of these scenarios would require tremendous amounts of time and resources. Still, energy companies need to prepare as best they can. Companies should at least conceptualize the scariest scenarios they can think of (though if they can conceive of them, they probably are not "black swans") and assume those still are not the worst cases. Some of these scenarios might look like climate change impacts (e.g., extreme heat events, bigger storms); it is not clear that the industry is fully grappling with scenarios that may seem crazy now but that may come to pass in a world that surpasses a 2°C target. Companies should also plan for multiple events occurring at once – an exponential type of threat and risk. They need to think through what could go wrong and how those events might affect business. They need a plan for dealing with black swan events once they occur (e.g., crisis response plans), and then they also need backup plans, since the first plan probably will not work.

Many companies are woefully behind in thinking through such scenarios. Part of the challenge is that energy companies are not always able to get good information about what the threats are around the globe. There are efforts underway to improve collaboration on threat information sharing, such as to get clearances out faster to enable sharing of classified information. The FBI also does community outreach and has the InfraGard partnership program to share information on threats.

CYBER AND PHYSICAL THREATS

"Black swans" are often used as scapegoats when entities do not have good plans in place to deal with foreseeable cyber or physical incidents. These are not true black swan events; they happen all the time. Security is a continuum, and there are tradeoffs and judgments about how much security is enough. It is generally very hard to convince companies to pay for security for something they do not perceive as a danger (whether for cyber or physical threats), but they are usually willing to pay almost anything once a problem actually arises.

Physical threats to energy systems can come from nature or from people. Electrical substations have been attacked. Domestically, the largely unprotected domestic networks (e.g., the electric grid, water supply) face potential threats from groups such as sovereign state movements, militias, and ecoterrorism. There are numerous steps a company could take in promoting resilience, and it is possible that an effort in one area (e.g., hardening infrastructure) could be counter-productive in another area (e.g., recovery). Ideally, companies would find a way to optimize holistically.

Cybersecurity threats, meanwhile, are a source of increasing concern; they are foreseeable and happening. There are hundreds of thousands of cyberattacks happening every day, and a large percentage of hacking attacks are on the electric grid. Cyberattacks on electricity grids generally are not coming from the hacker community, but rather from governments. A cyberattack caused outages in the Ukraine grid; that attack had been planned for more than a year and involved information stolen through corporate email, HR systems, and people disguised as employees requesting information. The attack was not on the SCADA system directly, but rather came in through other systems; cross-communication among systems can be a big issue.

Security is a continuum, and there are tradeoffs and judgments about how much security is enough.

Insider threats are the most likely way bad actors can get into a system, yet most companies do a poor job of preparing to face insider threats. Most do little background investigation or vetting of new hires, much less re-vetting of existing employees (e.g., reviewing social media profiles to gauge whether any employees have been radicalized). There is rarely a security officer in companies responsible for these kinds of activities. Entities with robust approaches to dealing with insider threats tend to continually monitor systems, check people constantly, and train employees about how to behave and what to look for in terms of other people's behavior.

While there are malicious insiders, the bigger threat is the accidental insider who unknowingly provides access. Most systems are fairly easy to penetrate, and it is usually possible to get into a system through human error. Education is hugely important and often overlooked. Employees taking computers home onto less secure networks is one of the ways they get infiltrated; personal devices connected to work infrastructure represent a huge risk. Similarly, teaching people not to put thumb drives into their machines is important. A really high percentage of access is achieved through phishing attacks, so it is also important to educate employees about these attacks and what not to do; it only takes one or two employees to click on a phishing link to expose a system to attackers. Companies are very good at training employees on their safety culture, and they need to build a cybersecurity culture as well.

The basic steps, such as education, backup systems, firewalls, and virus scans, are all important, but the days of focusing on perimeter defenses may be over. There are two types of companies: those who have been hacked and those who do not know it yet. (Cyberattacks are sitting in systems for hundreds of days before being detected.) In addition, there are currently anywhere from five to six billion internet-of-things (IoT) devices connected to the grid – that figure will likely increase by a factor of five in the near future – and it is likely that there will be an unsecured IoT device breach that affects the grid in a material way over the next few years. Companies have to assume their systems will be or are already compromised and have to figure out how to function and develop work-arounds. Some threats will get through, so efforts may be better spent on boosting system resilience and restoration than on up-front security. It may be better to plan for the response than to prevent the attack.

Companies have to think about what would happen if bad actors got into their systems and what damage they could do. It may be advisable to set up virtual separation in the system, where attacks can affect only some aspects of the system but not the mission critical parts. Companies have to figure out the core things they want to protect; those items should not be put online, should be encrypted, or should otherwise be protected. In addition, efforts to promote early detection – reading anomalous signals in seconds or milliseconds – would be valuable. In general, there may be a need to allow for graceful degradation, rebound, and response – detecting the threat, isolating it to the extent possible, preserving the rest of the functions as much as possible, and then focusing on getting the threatened part back online. Being a hard target is also a good way to prevent attacks; if a system is hard to get into, can respond quickly to attacks, and can limit damage, it is a less attractive target.

More broadly, it is essential to incorporate resilience into the way the grid is built and operated. The key time to think about this kind of structural and operational resilience is when so much money is being invested in modernizing the grid. Possible approaches include microgrids, having fewer big critical substations, and having greater redundancy and optionality. For instance, Princeton University built a microgrid to sell energy, frequency regulation, and other services in the PJM market, but during Superstorm Sandy, it islanded and became an emergency center for the whole region. Storage can also help provide resilience to the grid; grids become unstable when they get voltage or frequency fluctuations, and battery storage coupled with smart inverters can play a key role in providing real and reactive power services for feeder capacity relief, volt/var optimization, synthetic inertia, and other purposes that are critical for stability in pockets of the grid. This more decentralized, modular way of running the grid means that an event can be more readily isolated, cascading problems can be avoided, and restoration of smaller nodes of the grid can happen more quickly.

It could also be enormously beneficial to create reserves of critical equipment to enhance system resilience. The industry, for instance, is looking at creating strategic transformer reserves. Grid Assurance is a new subscription-service collaborative effort of utilities and energy companies trying to develop an inventory of hard-to-replace transmission equipment. A key challenge is that all transformers are custom-designed and custom-made. Similarly, no two substations are designed in the same way, making them difficult to replace as well. There would be real gains from standardizing the system and promoting more modularity to enable easier swapping out of equipment; the more transmission can be standardized, the more sharing there can be. Nationally, the United States lacks an inventory of transformers that could be available as replacements if several went down due to a big weather, geomagnetic, or attack event; a Strategic Transformer Reserve could be a good idea, if Congress would actually fund it. (The FAST Act has the Department of Energy exploring whether the federal government should do something similar, though encompassing a scope broader than just the grid.)

Resilience has value to the Department of Defense in a way different from other customers. The military is planning not just for outages of a few hours or days from weather events, but also for physical and cyberattacks that could lead to outages of months. Currently, some Department of Defense installations have utility-connected power and diesel generators as backup for specific needs. In the future, mission-critical installations will still depend on the utility grid, but they will also have many sources of distributed generation that are dedicated or dedicatable to the installations, as well as an understanding of which loads can be adjusted or shed during outages. The focus is on achieving cost-effective, resilient, clean power, which includes strong infrastructure, microgrids, and multiple sources of power – with a preference for renewable energy, which has a fuel supply that can never be cut off. An islanded microgrid that could tap into local renewables to keep charging a battery system could represent a very long duration solution for outages (at least to cover some loads).

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REGULATING SECURITY & RESILIENCE

There have been numerous efforts over the years to ensure the security and resilience of the grid. Spurred by the 2003 blackout, the Energy Policy Act of 2005 marked the first time there were mandatory reliability standards for the bulk electricity system, enforced by the North American Electric Reliability Corporation (NERC). The basic reliability standards (and enforcement of them) are now part of the normal operating regime of electric companies. EPAct

2005 also gave FERC authority to approve mandatory cybersecurity reliability standards, and FERC is now on the sixth iteration of those standards. There are physical security standards as well, and there is work underway to address issues such as geomagnetic disturbances and solar storms.

There is also other critical infrastructure under threat (e.g., the gas network, the water network) that will require work across sectors. With the increasing reliance on natural gas as the global energy system decarbonizes, the fact that the gas network has no mandatory standards or structure like the electricity network presents a problem. In some regions (e.g., New England), loss of a big electrical asset is likely less of a risk than loss of a gas pipeline; unlike coal, which can sit in a pile, gas is a just-in-time fuel, meaning interruption of its delivery infrastructure presents a big risk. Federal agencies and ISOs are starting to incorporate these kinds of fuel risks into planning modalities.

FERC standards, given the procedural requirements (e.g., notice and comment), are basically a three-year process, which means they are not well adapted to fast-moving changes, such as the constant new forms of ransomware, malware, or other threats. There are questions about the feasibility of creating self-updating standards or other approaches to create a more efficient, less expensive, smoother process for a fast-moving world.

Beyond standards, there is an alphabet soup of government agencies, public-private partnerships, and voluntary collaboratives that have been set up to share information and respond to threats to the electricity grid. For instance, some in the industry are beginning to look at cost-effective risk mitigation strategies to deal with the risk of electromagnetic pulses (EMPs). In addition, last December, Congress passed some measures to make sharing cybersecurity information easier for agencies and industry. State regulators, however, do not have the kind of resources and infrastructure that FERC does to look at cyber threats, and there is a need for an improved state-federal partnership to address risks to the bulk electricity and distribution systems.

APPENDICES: AGENDA

SUNDAY, JULY 3

9:00 – 9:30 AM	**Introduction**	**David Monsma**, Executive Director, Energy and Environment Program, The Aspen Institute
	Co-Chairs Welcoming Remarks	**Anne Pramaggiore**, President and Chief Executive Officer, ComEd, and Clint Vince, Chair, US Region Energy Practice, Dentons US LLP
	40th Anniversary Lookback	**Jack Riggs**, Senior Fellow, Energy and Environment Program, The Aspen Institute

9:30 – Noon **SESSION I: Overview – Emerging Trends in Energy Markets**

How have energy markets reacted to sustained low prices of oil and natural gas? How are global pricing impacting US energy markets?

Moderator: Clint Vince

Discussants:

Global Energy	**Jason Bordoff**, Founding Director, Center on Global Energy Policy, Columbia University
Trends in the US Power Sector	**Karin Corfee**, Managing Director, Navigant
Carbon Reduction Policies	**Julio Friedmann**, Senior Advisor, Lawrence Livermore National Lab
The State Of The US Utility	**Anne Pramaggiore**, President and CEO, ComEdison
High Noon in the Wild West	**Bob Stump**, Chairman, Arizona Corporation Commission

1:30 – 4:30 PM **SESSION II: Evolution or Revolution – A look at the Changing Utility Model**

The business model of the utility is changing, and it is changing quickly. What are strategies that work for paying for core grid functions while distributed generation continues to grow? Will domestic electricity demand continue to be flat or will energy efficiency bend the curve downward?

Moderator: Anne Pramaggiore

Discussants:

The Utility Business Model – The Future is Now	**Sue Tierney**, Senior Advisor, The Analysis Group
The Future of the Utility Industry	**Stuart Hemphill**, Senior Vice President, Customer and Operational Services, Southern California Edison
Development of a Western Grid- Can We All Just Get Along?	**Jonathan Weisgall**, Vice President, Government Relations, Berkshire Hathaway Energy
Rates and Pricing	**Jeff Gleeson**, Head of Energy Partnerships – West, Nest Labs

6:30 – 9:30 PM **ASPEN INSTITUTE ENERGY POLICY FORUM 40TH ANNIVERSARY CELEBRATION**

Aspen Mountain Club

DINNER PROGRAM: OUR CHANGING ENERGY LANDSCAPE

A special conversation featuring:

Andy Baynes, Head, Global Energy Partnerships, Nest Labs

Jim Rogers, Chairman, President and CEO, Duke Energy, (ret.)

Moderated by **Jack Riggs**

MONDAY, JULY 4

8:30 AM – 11:30 AM **SESSION III: Infrastructure Resilience and Security**

Resilience and security have become buzzwords in the post-Hurricane Sandy and Metcalf Transformer Attack world, and in light of recent cyber-attacks by both State and Non-State actors. What are states, cities, and utilities doing to prepare for the risk of attack and extreme weather events in the shorter term, and climate change impacts in the longer term?

Moderator: Anne Pramaggiore

Discussants:

Black Swan Scenarios – What Could Go Wrong?	**Kevin Hulbert**, Senior Advisor, Dentons, and former Senior Intelligence Official, Central Intelligence Agency
Cyber and Physical Security	**Cheryl LaFleur**, Commissioner, Federal Energy Regulatory Commission
Storage and Resilience Planning	**Kelly Warner,** President, Advanced Microgrid Solutions
The Role of the Military in Energy Resilience	**Mark Correll,** Deputy Assistant Secretary, Environment, Safety and Infrastructure, United States Air Force

TUESDAY, JULY 5

8:30 – 11:30 AM **SESSION IV: Low Carbon Technology**

The landscape of energy is changing. Levelized cost of electricity for renewables, particularly on-shore wind, is increasingly competitive with gas, coal, and nuclear, and the cost of electric vehicles and hybrid gasoline-electric vehicles are competitive. What will the future mix of low-carbon technologies look like in the U.S? What are the technologies on the horizon likely to be game changers?

Moderator: Clint Vince

Discussants:

Convergent Energy Disruptions	**Amory Lovins**, Co-founder and Chief Scientist, Rocky Mountain Institute
The Technologies Needed for a Clean Energy Revolution	**Brian Gutknecht**, Chief Marketing Officer, GE
Accelerating the Transition to Sustainable Transport	**Diarmuid O'Connell,** Vice President, Tesla
Modernizing the Grid for a Low-Carbon Future	**Bryan Hannegan**, Associate Director, National Renewable Energy Laboratory

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