2017 ENERGY POLICY FORUM

DISRUPTIVE FORCES AND THE ENERGY SYSTEM'S RESPONSE TO CHANGE

Ernest Moniz & Anne Pramaggiore, Chairs

Dave Grossman, Rapporteur

THE ASPEN INSTITUTE
ENERGY & ENVIRONMENT
PROGRAM

The Aspen Institute is an educational and policy studies organization based in Washington, D.C. Its mission is to foster leadership based on enduring values and to provide a nonpartisan venue for dealing with critical issues. The Institute has campuses in Aspen, Colorado, and on the Wye River on Maryland's Eastern Shore. It also maintains offices in New York City and has an international network of partners. *www.aspeninstitute.org*

The Aspen Institute Energy and Environment Program is an active and prominent convener of non-partisan policy dialogue and neutral forums focused on key energy and environmental topics and how to advance environmental sustainability in a technological world. The Program's mission is to take-up the enduring questions about nature and society, and to prompt new thinking among diverse participants by deliberately testing assumptions and policies about sustainable water use, clean energy, climate change, and wildlife conservation. The Program promotes values-based dialogue between thought leaders from business, government, NGOs, and academia to address complex energy and environmental policy challenges in a collegial atmosphere that allows deliberation, creativity, collaboration, and compromise to flourish. Like the Aspen Institute as a whole, the Energy and Environment program seeks to inspire and explore new ideas and provoke action in the real world.

For all inquiries, please contact:

Energy & Environment Program
The Aspen Institute
One Dupont Circle, NW | Suite 700
Washington, DC 20036
Phone: 202.736.2933
Fax: 202.467.0790

The Aspen Institute
One Dupont Circle, NW | Suite 700
Washington, DC 20036

Published in the United States of America in 2017 by The Aspen Institute

TABLE OF CONTENTS

FOREWORD

The energy system is in a constant state of change. New technologies are researched and developed. They are piloted. Then, if they meet the needs of the marketplace, they are deployed. The system responds to new technologies by adapting and integrating. The attributes we seek in an energy system also change. We want a system that is reliable, resilient, secure, affordable, and clean. This year we looked at a diverse cross-section of topics at the forum, including the role of baseload generation, distribution system policy and regulatory design, decarbonization, cyber-security, and the increasingly interdependent roles the US, Mexico, and Canada play with each other in energy.

Ernest Moniz, the 13th United States Secretary of Energy and now the Co-Chairman and CEO of the Nuclear Threat Institute as well as President and CEO of the Energy Futures Initiative, and Anne Pramaggiore, the President and Chief Executive Officer of ComEd, graciously dedicated their time and considerable expertise to make this forum as great as it was. The excellent discussants and participants made the agenda come alive with discussion and debate and made this among the best dialogues we have held in Aspen.

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 can continue to provide valuable high-level discussion.

SPONSORS

Com Ed   Nest

American Electric Power   Sempra Energy

Tellurian   Dentons

Itron   Navigant

Edison Electric Institute   Van Ness Feldman

Institute for Electric Innovation   NRECA

Electric Cooperatives of Arkansas   Northwest Energy   UT Austin Energy Inst

Neither the Forum speakers, participants, nor sponsors are responsible for the contents of this summary. Although this is an attempt to represent views expressed during the Forum, all views expressed were not unanimous and participants were not asked to agree to the wording.

Over the last four decades, 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.

David Monsma
Executive Director
Energy & Environment Program
The Aspen Institute

EXECUTIVE SUMMARY

The U.S. power system is in a period of disruption and transition. Renewables and distributed energy resources (DERs) have experienced astonishing technological innovation and cost reductions, leading to wider customer-driven and utility-driven adoption. The Internet of Things (IoT) and big data applications are also proliferating, and the "smart" devices already installed in American homes are just beginning to be used to deploy energy services at increasing scale. These trends open up multiple potential sources of value, depending on what particular DERs are designed to do and how they interact with the system. Measurement of DER value, however, is currently rather primitive, and there is no consensus on how to correctly measure DER value; setting up compensation for DER value can also create tensions between cost-of-service models and value-of-service pricing. While DERs provide the potential for great value, they also have the potential to inject new volatility into the grid; distribution utilities will have to make sizable investments in grid observability to maximize the benefits of the new suites of distributed energy technologies.

The disruption caused by increased penetration of DERs will require new business models, markets, financing, and regulations. As the grid becomes more decentralized and bi-directional, value in the industry is shifting from generation to distribution and behind-the-meter retail. Utility CEOs are rapidly making investments in DERs, pursuing DER integration pilot projects, and buying or partnering with technology, data, and device companies. Possible utility business models include "energy as a service" (in which utilities provide customers with supply, demand, and energy optimization services) and network orchestration (in which utilities bring together the ecosystem of players and manage the platforms on which sets of technologies operate). At the same time, the rate base and regulatory jurisdiction are starting to push beyond the meter as well, and regulators – though constrained politically by constituencies, governors, and statutes – are beginning to wade into the issues surrounding transformation of the distribution grid.

There are many types of resources that could be considered "baseload" under various definitions, and it just may not be a helpful term anymore.

As for the U.S. bulk power system, the continuing relevance of the "baseload, intermediate, peaker" paradigm is unclear, as exemplified by current debates about baseload generation. Although the concept of "baseload" remains a focal point of federal, state, and public debates about electricity, there are many types of resources that could be considered "baseload" under various definitions, and it just may not be a helpful term anymore. The historical understanding of "baseload" (i.e., coal and nuclear) is being challenged by greater competition from new supply resources, with "zero"-marginal-cost renewable energy resources and low spot prices for natural gas now driving the market. The bulk power market is also being challenged by some of the same forces affecting the distribution grid, including increased penetration of DERs, little or no growth in electricity demand, and other developments behind the meter that affect the shape of the demand curve.

Whether or not energy resources are "baseload" matters less than the attributes those resources provide. Markets generally pay only for power and, with less uniformity, for capacity, but there is increasing interest in figuring out how to pay resources for their capabilities, which could include ramping ability, frequency response, and other essential reliability services There are also other important attributes less directly related to grid functionality, such as being zero-carbon, that are not currently valued in markets, and some attributes, such as the national security and rural employment implications of a domestic nuclear power industry, are virtually impossible to price methodologically (though not politically). Listing attributes is thus much easier than figuring out how to actually price and create markets for the values and services provided by electricity system assets.

As the U.S. grid evolves, security – particularly cybersecurity – has become a growing concern. Utilities are getting hacked thousands of times a day, and new networked IoT devices can create cyber vulnerabilities. Even measures taken to enhance grid reliability, such as increased automation and improved sensing and monitoring, can simultaneously create additional cyber vulnerabilities. In response, the industry and the federal government have initiated a range of efforts to boost cybersecurity. Investor-owned utilities are working closely with each other and with municipal utilities and co-ops to analyze information, prevent cyberattacks, and respond if an attack is successful. The industry is also coordinating with the government to share information on evolving threats. There are enforceable federal cybersecurity standards on the bulk power system, and the Department of Energy (DOE) has provided cybersecurity support to distribution utilities, public power, and co-ops. Still, clearer legislative authority and increased budgetary resources are needed to support the Department of Energy and the Federal Energy Regulatory Commission (FERC) in their efforts to promote cybersecurity and grid reliability.

Clearer legislative authority and increased budgetary resources are needed to support the Department of Energy and the Federal Energy Regulatory Commission (FERC) in their efforts to promote cybersecurity and grid reliability.

The evolution of the U.S. grid is occurring in the context of a global push to address climate change. The scale of decarbonization needed to reach the climate targets set out in the Paris Agreement is much greater and much harder to achieve than many people might recognize. The initial commitments made by countries under the Paris Agreement are only a first step. In the United States, deep decarbonization of the economy will require a portfolio of innovative technologies, markets, financing, a carbon price, and sector-specific policies at the federal, state, and local levels. Anticipated building blocks of deep decarbonization in the United States include energy efficiency (in transportation, buildings, and industry), decarbonization of electricity (including renewables, carbon capture and storage, and nuclear energy), fuel switching (e.g., electrifying transport and heat), and enhancing efforts to remove carbon dioxide from the atmosphere through both biological and engineered systems. The advent of the Trump Administration will make achieving deep decarbonization in the United States (and globally) even more challenging, so sub-national actors such as cities may have to become even bigger sources of decarbonization progress. While U.S. decarbonization actions are critical, it is the developing world that will truly determine the fate of climate change and the Paris Agreement. China's development pathway, in particular, could shape the future of climate change, and there are reasons to be both pessimistic and optimistic about China's ability to achieve deep decarbonization.

The developments in the U.S. grid over the past few years have also occurred during a period of increased energy integration among the three North American countries, both bilaterally and trilaterally. Canada and the United States have a long history of energy integration and a symbiotic network, building on each country's respective strengths and attributes, though the relationship is not without its points of contention. Mexico has a much smaller energy relationship with the United States than Canada does, with energy integration focused on natural gas moving south, although electricity connections are increasing. The North American countries have collaborated on grid security and resilience, as well as on promotion of clean energy and climate initiatives. It is unclear, though, what will happen to trilateral commitments that do not fit with the Trump Administration's policies, such as the continental clean energy target. More broadly, the President's focus on trade deficits and immigration could create tensions between the United States and its neighbors, particularly Mexico, and threaten the regional integration seen in recent years.

THE ELECTRICITY DISTRIBUTION SYSTEM, DERS, AND VALUE CREATION

In the United States, renewables and distributed energy resources have become cheaper and more widely adopted. Energy efficiency is leading to a new normal of flat or declining load growth. The grid is starting to become smarter, more multi-directional, and more transactional. These developments have significant implications for the electricity distribution system and the value it provides.

DEPLOYMENT OF DERS AND THE INTERNET OF THINGS

DERs can include a range of technologies, but the term is generally considered to include energy efficiency, demand response, storage, distributed generation, and other behind-the-meter technologies. DERs are growing three to five times faster than central station generation, a big shift that will necessitate changes in business models, markets, financing, and regulations.

The pace of technological innovation and cost reduction has been astonishing – and it is continuing. For instance, energy storage deployment appears to be accelerating, and the costs of energy storage have dropped significantly. Lithium-ion batteries are working and affordable in some applications, and utilities are researching how best to connect, optimize, and control them. While storage more broadly can currently help with sub-day grid functionality (e.g., minutes), storage that is multi-day or seasonal is nowhere close on the horizon. There are hopes for some revolutionary type of chemistry that allows for longer and larger energy storage.

The pace of technological innovation and cost reduction has been astonishing

The Internet of Things and big data applications are also proliferating, and some think IoT has already hit a tipping point. While it will likely take a decade or more for the existing fleet of conventional devices to turn over, customers are increasingly adopting "smart" devices. Almost one-third of Americans have already purchased some kind of IoT device, and as the devices continue to get cheaper, there are expected to be trillions on the system. The IoT space is still a messy one for consumers, but different brands in the industry are increasingly figuring out how to connect with each other. Utilities can play a big role in guiding customers towards the devices that make sense for their homes and for the grid.

While utilities and regulators are pursuing lots of small-scale IoT pilots, there are millions of smart thermostats and other smart devices already installed in American homes that can be used to deploy energy services at scale. These devices can provide flexibility, dispatchability, and reliability, depending on the algorithms deployed. For example, algorithms can be pushed out to all devices in a utility territory, which, through machine learning, can create customized algorithms for every home to maximize energy efficiency. These devices can also pursue more aggressive efficiency during set utility peak hours, integrate with rates to optimize customer usage, participate in demand response programs, and shape loads. In addition, since IoT devices can respond to very dynamic price signals much more easily than customers can, rate designs can become much more complex if desired, to facilitate different types of value streams. All in all, utilities are barely scratching the surface of the opportunity for more granular control, greater flexibility, asset-level analysis, and hyper-local, customized responses to grid needs. While grid benefits are just starting to be realized at scale in a few places, truly leveraging IoT devices to provide grid benefits at scale will require changes in policy, more innovation, and a willingness to move to a more flexible electricity system.

Technological innovation is by no means limited to storage and IoT devices, as there has been significant innovation in a range of other DERs, including rooftop solar, smart inverters, and more. There are many more innovations on the horizon as well, including on energy efficiency, distributed generation, and customer interaction.

The proliferation of DERs has the effect of exporting the constraints of the grid onto consumers.

The deployment of DERs raises some challenges, however. At a philosophical level, the proliferation of DERs has the effect of exporting the constraints of the grid (e.g., peak, ramping) onto consumers, raising the question of whether consumers should be serving the grid or vice versa. At a more operational level, DERs, especially solar photovoltaics (solar PV), are changing load shapes and injecting new volatility into the grid. The deployment of DERs is also happening in many cases without design or plan, yet dispatching the range of DERs in an uncoordinated way, especially at larger scales, could threaten reliability. Additional coordination problems can arise in areas where there are multiple competing DER aggregators inter-penetrated in service areas. Especially at high penetration, all of the distributed resources have to work together to ensure grid reliability, which requires increased distribution automation and greater visibility. There is amazing visibility today in the bulk power system that did not exist 15 years ago, allowing visibility into real-time congestion and sometimes pricing, and distribution utilities would have to make enormous investments in the same kind of grid observability to maximize the benefits of the new suites of technologies.

VALUING DERS

DERs are being deployed through two different approaches. One approach is customer-driven adoption, as is the case with most residential rooftop solar deployment. The other is utility-driven adoption, as utilities deploy DERs in locations where they benefit the grid. These approaches have different implications for the value of DERs, who benefits, and who pays.

DERs could benefit customers, the grid, the power supply system, and/or society as a whole. The benefits of a smart electricity distribution grid accrue to different parts of the electricity system, but the investment happens almost entirely at the distribution level. Utilities reasonably question whether it is realistic to recover their investments in grid enhancements that have to be made now in order to make a more distributed, dynamic system work.

DERs can provide multiple potential sources of value, both positive and negative, depending on what the DERs are designed to do and how the DERs interact with the system. Different DERs have widely varying load profiles, providing power to the system in very different ways. Some DERs can provide sub-day reliability, while others cannot. DERs also vary widely in terms of the length of asset lives. Value depends on the interaction of the attributes of the resource (e.g., timing of the output, dependability, types of resources being displaced, quality of the power) and its location on the system.

Measurement of DER value is currently rather crude. Typically, DER value is administratively determined, as with the rather blunt tool of net energy metering. There is no consensus, however, on how to measure DER value precisely and well, though it is generally preferable to be technology-neutral and to take into account market signals, location signals, and temporal signals. DER customers should probably pay for the costs incurred by the system to provide them with energy and for the use of the grid to send power out. DER customers should also be compensated (perhaps out of a different pot) for what they are providing to the system. When the price for the grid, for electricity, and for other services are all pushed together into retail rates, customers are not seeing what is actually happening in the system, which feeds misleading narratives such as rooftop solar customers not using the grid.

Separating out the various values and services, however, is challenging for many reasons. For one thing, when utilities propose separating out the various aspects, they get accused of being anti-solar. Setting up compensation for DER value can also create tensions between cost-of-service models and value-of-service pricing, as the full value of a resource is not usually the same as the compensation for it. (The various "value of solar" studies being rolled out in various places are more like cost-benefit analyses than methods for compensation.) In addition, there are many values that are hard to quantify and monetize, such as reliability, rapid recovery capability, and social indicators such as job impacts and community air quality.

There are also challenges related to the fact that DERs can provide value to both the wholesale and retail markets. For starters, how exactly DERs can collectively participate in wholesale markets has been a matter of contention, partly because of transmission and distribution control coordination issues and partly because of debates about federal jurisdiction over DERs. Markets also make it hard to have two-level market arrangements – using the same asset for different purposes. For instance, if DERs switch load off-peak, then at the wholesale level, there is no need to buy peak power, while at the distribution level, there may be no need to build a new substation. Figuring out how to coordinate and assign value to those kinds of two-level arrangements will require much more discussion.

UTILITY ADJUSTMENTS

The old utility business model is no longer profitable or sensible in a distributed, digital world with flat demand. Utilities need new business models that rely less on getting compensated for spinning meters. The industry is well aware of this. Surveys of the power industry have found that the industry views existing regulatory models and rate structures as its greatest current challenge, followed by flat or declining load growth. Both of those put a great deal of pressure on utilities to find growth and new opportunities for value. Looking forward, the power industry views the increased penetration of DERs and renewables – particularly DERs – as a major disruption. This new world requires new business models, redesigned markets and regulations, and changes in core utility planning processes such as load forecasting.

As the existing grid moves towards becoming an increasingly clean, decentralized, intelligent, bi-directional "energy cloud" system, value in the industry is shifting from generation to transmission, distribution, and behind-the-meter retail. A trillion-dollar global market is being created at the edge of the grid. While some utilities are still very interested in large baseload generation, and many have embraced utility-scale, centralized renewable generation, utility CEOs are also rapidly making investments in DERs and are buying or partnering with companies that provide technologies vital to operating in an energy cloud. Some utilities are pursuing pilots related to integrating a range of DERs (e.g., microgrids, community solar, battery storage, fuel cells), sometimes including giving the utility control over the DER devices. Managed charging of electric vehicles (EVs), for example, could serve as a demand resource; even with a relatively small deployment of EVs, they could provide a lot of capacity and could be used for frequency response, peak shaving, and other services. These DER pilots help utilities understand not only the DER technologies, how scalable they are, and how they interact with the grid, but also how the utilities will benefit, how customers will benefit (and pay), and how the whole arrangement will work in terms of cost and value.

Regulatory and business model changes will be needed in order to allow the value provided by DERs and the energy cloud to translate into sustainable and profitable businesses. "Energy as a service" is one possible strategic pathway to value creation in the energy cloud. It is a $17 billion market in the United States now and is expected to grow to

$40 billion over the next decade. Under this business model, utilities provide customers with supply, demand, and energy optimization services. Regulators are mostly letting utilities experiment with behind-the-meter services, while remaining wary of major changes; public power entities and co-ops, which are unregulated, have a bit more freedom to experiment and are generally well ahead of the investor-owned utilities in this transformation (though they also have their own constraints, including vocal voters and bondholders that have to be paid). Hybrid utility models are also emerging, with some services happening on the regulated side and others being better provided by the market.

There is a lot of investment in "energy as a service" at the moment, as well as significant mergers and acquisitions activity, as larger companies push to provide more comprehensive offerings. Utilities can fill several roles in the "energy as a service" value chain, including overseeing the portfolio, market operations, and ongoing management. Their third-party partners, in turn, can find value in manufacturing and providing equipment, construction and engineering, financing, and asset operation and maintenance.

Technology will be a key driver of the infrastructure and business model transformation.

Another possible strategic pathway to value creation in the energy cloud is a platform model. It is hard to scale and build a sustainable business around individual technologies, as margins will erode more quickly over time. Instead, utilities can play an orchestration role, bringing together the ecosystem of players and managing the platforms on which sets of technologies operate. Utilities can serve as intermediaries and providers of a broader platform, integrating, aggregating, and dispatching the range of DERs and other resources on the system. This could include bringing together building-to-grid integration, transportation, smart cities, communications, and other elements. The overlay of digitized networks on energy assets gives utilities situational awareness, the ability to better engage customers, and the opportunity for new revenue models. With all the products and services being sold, utilities can be the enabler of all and the actual doer of some.

Technology will be a key driver of the infrastructure and business model transformation. Technology dictates what is possible. Utilities will be enabled by technology, but most will never become technology companies. Utilities will have to pursue a wide range of partnerships involving technology, data, and device/appliance companies. Potential disruptors can become utility partners, and utilities need to pick the right partners to aggregate a portfolio of solutions. Utilities also tend to use a very small percentage of the data they have available and might benefit from opening their data to researchers, manufacturers, and others to develop products and services for utility customers. There is a huge commercial ecosystem moving around this transformation, with energy incubators, lots of private money, and the unregulated subsidiaries of utilities becoming some of the most active players (though unlike other disrupted sectors, there are few new companies and billionaire entrepreneurs that everyone knows in the energy space).

Technology will also drive utility-customer interactions. Some of this will involve artificial intelligence, machine learning, and interfaces with DERs. It will also involve data analytics in social and behavioral sciences, which will help utilities and their partners better understand, target, and interact with customers, enabling more complex interactions, better identification of which customers are willing and able to participate, and provision of more value-added services. (This also, of courses, raises issues of data privacy and ownership, which some customers still feel very strongly about.)

Utilities (and their investors and regulators) are somewhat inhibited in these technological pursuits by a long culture that is antithetical to encouraging innovation and taking risks on big ideas. Generally speaking, traditional utility regulation has trained utilities for a century to be risk averse, prudent, conservative, safe, and reliable. That being said, utilities and others in the industry are doing more innovating than one might expect, and their investors, who recognize the challenges of flat demand, are looking for new ways for utilities to create new revenues.

Some technology companies could theoretically seek to supplant utilities, providing all services to customers and selling the utility relevant data about load, though there are regulatory obstacles to such an approach. How the regulatory framework evolves will determine who can compete. In addition, many technology companies may not want to be universal service providers, as utilities have to be. Electricity is a favored commodity and a public good, and a policy decision was made that everyone should have access. Even in the midst of rapid technological change, utilities have to meet their social compact obligations to their customers, many of whom may struggle with paying their electric bills. Other businesses can serve only particular segments of customers – and some of the DER products and value creation ideas being considered are not necessarily intended for everyone – but utilities do not have that luxury. Utilities are responsible for the country's most important infrastructure and have to provide safe, affordable, reliable power to everyone.

Utilities are, however, now facing more complex customer needs and expectations beyond providing long-term, least-cost, least-risk energy, including demands for high levels of sustainability, reliability, stability, and customer participation. There is also a need to condition the market and prepare customers for a world with a much more dynamic, distributed grid. While some customers want to get involved in the nitty-gritty details of managing their energy use, many customers would be happy with devices that can take real-time pricing and other information and then make decisions for them about when to bring various power loads online. Most consumers will not understand or care about the complexity involved in ratemaking and integration in a dynamic grid, just as the average customer gives no thought now to the complex electricity system that already exists. Utilities have to strive to provide elegant solutions to their customers in the context of complexity.

Utilities are, however, now facing more complex customer needs and expectations beyond providing long-term, least-cost, least-risk energy, including demands for high levels of sustainability, reliability, stability, and customer participation.

REGULATORS

As value in the industry shifts from generation to transmission, distribution, and behind-the-meter retail, the rate base and regulatory jurisdiction are starting to push beyond the meter as well. Much of the actual change needed in the system will happen because of state regulatory commissions. Regulators are beginning to wade into the issues surrounding transformation of the grid, but they are constrained. Some arrive in office with limited electricity experience, and given the complexity of the electricity system and its transformation, coupled with the fact that regulators often have very thoughtful people providing completely opposite comments, it can be challenging to encourage them to invest in grid modernization. Even the many regulators who are informed and eager to move forward on these issues are constrained politically by constituencies, governors, and statutes. Regulators, for instance, are generally charged by law to look at cost, not value; they live in a cost-of-service paradigm.

Given the key role regulators will have to play in the transformation of the grid, some utilities and others in the industry are starting to bring more of their innovation people to focus on addressing regulatory obstacles. For instance, at the moment, there is a total absence of standardization around how to collect data from thousands of different utilities, which is a big impediment to the advancement of IoT. Regulators will be pivotal in addressing that impediment. Similarly, although grid storage could provide the distribution system with buffering capability and make it more resilient and flexible, such an outcome is inhibited by regulations on distribution utilities that view storage efforts as engaging in commodity energy transactions. Legislative changes, as well as improved regulator education and greater support and encouragement, are needed to enable regulators to tackle some of these challenges.

THE FUTURE OF BASELOAD

A few decades ago, the lineup of resources on the electricity system had relatively clearly defined roles: baseload, intermediate, and peaker. The continuing relevance of that whole paradigm is far less clear today, as exemplified by current debates about baseload generation.

THE CONCEPT OF "BASELOAD" RESOURCES

There is no standard definition of baseload generation. In the early days of the industry, the task was to design the lowest-cost system, and baseload was thus historically correlated to merit-order dispatch; it was generally defined in terms of the fuel types – coal and nuclear – that were the cheapest in the stack.

There are many definitions of "baseload" today. For instance, one could define it to include resources that have high capacity factors and are not easily rampable. The term could also encompass the types of resources that technologically and economically make sense to keep on the vast majority of the time – basically, 24/7 generation – which allows for simplified grid management. Under such definitions, baseload generation could include resources such as coal, nuclear, natural gas combined cycle, big hydro, and renewables with economicly viable integrated storage. It is important to recognize, though, that no resource works 24/7/365; everything breaks or stops producing at some point, for different reasons

DEFINING 'BASELOAD'

- **Baseload = lowest demand over course of year**
- **Baseload = paid-off capacity**
- **Baseload = power plants that ramp slowly**
- **Baseload = coal, nuclear**

Conclusion: the word "baseload" is now obsolete, and possibly even damaging

Source: Michael Webber, UT Austin

Although the concept of "baseload" remains a focal point of federal, state, and public debates about electricity and support for various resources, it may not be that helpful a term anymore. Whether or not energy resources are "baseload" matters less than the attributes those resources provide. Designing the lowest-cost system today, optimized for a range of attributes, would yield a very different power system than it did in the early days of the industry, given the wide range of technologies and the much greater ability to control those technologies. In fact, it is conceivable that technological innovation and the growing penetration of DERs will push mature markets to start commercializing flexibility and more dynamic, complex, and localized services – perhaps to the point that DERs become the "baseload" and the grid becomes the margin. It is worth considering which approach to "baseload" is cheaper for society, more inclusive, more resilient, and more reliable.

Utilities generally are not investing in baseload generation now unless they absolutely have to, as there is no certainty about where the market is heading. Those who stepped out to invest in new baseload in 2008 – when there was talk of a nuclear renaissance, scarce natural gas, clean coal technology, and growing load – did not do so well with those investments.

CHALLENGES FACING "BASELOAD" POWER

Clearly, the historical understanding of "baseload" is being challenged in several ways. For example, there is greater competition within the bulk power supply sector as new resources come online, while traditional baseload resources are experiencing rising capital and operating costs due at least in part to environmental and safety regulations.

Public policy over the years has heavily influenced the bulk generation market in the United States, at various times boosting or constraining nuclear, coal, and gas plants. Recently, federal and state policies have helped spur the growth of renewable generation. State renewable energy mandates, for example, have forced the new entry of capacity into markets where there is sometimes no need for new capacity; resources are coming online in some places to meet policy imperatives (e.g., decarbonization) and/or to capture financial incentives. For instance, with all the mid-day renewables in California, there is no need for "baseload" there; rather, there is a need for flexibility that can deal with ramping and variability. The dramatically reduced cost of wind and solar generation also plans an important role.

At the same time, natural gas is growing its share of baseload generation. The innovation and structural changes that have occurred upstream in the United States suggest that the gas resource is likely to remain abundant and cheap for quite some time, though the increased reliance on natural gas in the electricity sector has raised concerns about gas price volatility. It is also conceivable that changes in the natural gas market, especially with increased LNG exports and an emerging global natural gas market, could have impacts on the U.S. electricity sector.

When bulk electricity markets originally started, peaker plants had higher marginal costs and set the marginal price, which meant baseload resources made a lot of money on infra-marginal rents, but the new market drivers are "zero"-marginal-cost renewable energy resources and low spot prices for natural gas, which are generally beating out everything else in the stack. Gas prices, for instance, are the main driver of low marginal prices in the Eastern United States, while new renewables, with marginal costs at zero (or below, with tax credits), play a non-trivial role in California. Low energy prices are putting certain types of incumbent generation in peril. Super-low marginal costs and an excess of peak power appear on the surface to be good for customers, but they are a problem if they cause things to retire that are needed (though there is no evidence of any threats to reliability). Economists would say there is oversupply and that some resources should be exiting the market.

The new market drivers are "zero"-marginal-cost renewable energy resources and low spot prices for natural gas.

In addition to greater competition within the bulk power supply sector, the bulk power market is at the same time being challenged by some of the same outside forces affecting the distribution grid, including increased penetration of distributed generation, little or no growth in electricity demand, and other developments behind the meter that affect the total level of demand and the shape of the demand curve.

The combination of additional competition and outside forces – driven by technological innovation, cost reductions, and a range of policy mandates and incentives – is creating other ways to meet 24/7 demand. For instance, one could rely on intermittent, variable, and other grid flexibility resources and leave it to the grid operator to integrate those resources in ways that meet demand. Such resources, which have varying costs, could include some mix of increased efficiency, demand response and other demand resources, more accurate forecasting for wind and solar PV, diversification of renewable energy by type and location, dispatchable renewable energy and co-generation, thermal storage, distributed electric storage (including EVs), fossil fuel backup (e.g., natural gas cycling), and bulk electric storage.

The bulk power system is in a very disruptive period. The existing system is not designed for unneeded new capacity coming online and very low marginal prices, and there will be a difficult, multi-year transition period. Current price levels and patterns are likely not what will prevail in the long run, and markets and policies should be designed for the long-run equilibrium state, not just for the current disruptions. A balance between planning and market forces will be key.

DESIRABLE ATTRIBUTES OR CAPABILITIES OF POWER

Those seeking to include particular resources in the mix keep looking for ways to support them. For some, this has led to a focus on the technology being "baseload", though as noted, focusing on whether or not a resource is "baseload" is not necessarily useful. It is more an outcome than an attribute; if the resource is doing what is greatly desired, then it will run a lot, but running a lot is not necessarily a needed attribute going in for reliable grid operation. Others focus on hard-to-define capabilities such as fuel diversity in order to support current "baseload" resources, though the electricity system is more diverse now than when it was 70% coal.

Rather than picking some set of favored resources and figuring out what capabilities could support them, a more honest approach to the challenge is to clearly define the capabilities that are needed to serve customers (and that customers will pay for) in a transparent and fuel-neutral way. Instead of paying resources for the volume of electricity they provide, there is increasing interest in paying them for their capabilities. These capabilities could include ramping ability, frequency response, black start, inertia, voltage support, and other essential reliability services. "Baseload" resources are generally very good at providing those, but other resources, such as batteries, can provide some of them as well.

There is increasing interest in paying them for their capabilities. These capabilities could include ramping ability, frequency response, black start, inertia, voltage support, and other essential reliability services.

The question is whether current markets are rewarding these and other attributes (e.g., location, flexibility) that were previously taken for granted – and if not, how they should. Markets generally are paying only for power and capacity, and some plants that provide a range of other services are closing down. Pricing attributes such as ramping ability appropriately would allow for assets themselves to be properly valued.

Reliability of the electricity system is the fundamental underlying attribute in many discussions about the future of baseload. With lots of change happening quickly, people are concerned about making sure the lights stay on, but existing institutional structures have strong incentives (and powers) to maintain and promote reliability. In any contest of attributes, it seems that reliability always wins, though there are costs to that (e.g., bigger reserve margins). The evolving nature of technology in the market, however, means there will likely be a different paradigm of reliability, which in turn requires changing capacity or resource adequacy policies. With new technologies and environmental priorities, it is increasingly difficult to identify years ahead of time what types of resources will be needed, where, and when, so it is unclear what obligation one is taking on in selling "capacity". This is leading to greater emphasis on "on demand" performance, with resource adequacy policies either emphasizing performance rewards and penalties (e.g., PJM, ISO New England) or identifying desired attributes and bifurcating capacity requirements (e.g., California).

There are several other important attributes less directly related to grid functionality that also are not currently valued in markets. Zero-carbon, for instance, is of rising importance and is, in fact, one of the reasons that traditional baseload generation is being challenged today. In general, the existing baseload system works well in providing safe, affordable, reliable power, but the mission to reduce carbon dioxide (CO2) has introduced new resources and questions about existing ones. The U.S. market is not set up, however, to support zero-carbon "baseload" generation, as evidenced by the serious economic challenges facing new nuclear plants and fossil fuel plants with carbon capture and storage (CCS). While there is talk in the electricity sector about the importance of decarbonizing, there are few mechanisms in place to price or value carbon, outside of low carbon prices in California and the Regional Greenhouse Gas Initiative (RGGI) states. Solving for carbon in the absence of a price on carbon is resulting in twisting regulations and piecemeal solutions, making the system more complex. Although national carbon pricing policy appears unlikely any time in the next few years, ISOs and RTOs could include a carbon adder in the cost of dispatch for each plant in the stack. Such a regional price signal could improve the economics of zero-carbon nuclear power plants, at least in terms of their competitiveness with natural gas. The broad authority of the Federal Energy Regulatory Commission over the wholesale market would also likely allow it to write an order approving a requested tariff that included a cost of carbon.

Listing attributes is much easier than figuring out how to actually price them and what the markets would actually look like, especially when some attributes are virtually impossible to price. Nuclear plants provide an excellent example. The health of the U.S. nuclear power industry is directly related to the country's ability to be a central player in international nuclear nonproliferation issues; there are questions about the leverage the United States has globally to advance non-proliferation and economic competitiveness if it lacks a vibrant domestic nuclear industry, supply chain, and cadre of U.S.-trained engineers. Nuclear plants also support good-paying jobs in rural areas. These economic and security benefits are really hard to price methodologically. Their value is undeniable, though. In fact the jobs angle helps drive the conversation in states regarding supporting existing nuclear plants, and the valuation of those jobs is therefore contributing in the political realm in the form of the level of subsidy (e.g., zero-emission credits) a state is willing to provide.

Solving for carbon in the absence of a price on carbon is resulting in twisting regulations and piecemeal solutions.

The focus on attributes suggests that not all kilowatt-hours are fungible. Markets alone, however, are unlikely to take a multi-decadal view, identify key attributes, and price them (especially the ones that are hard to define and price). There is a need for a combination of regional planning and market rules to find ways to pay for the values and services provided by electricity system assets.

GRID SECURITY

Fifteen years ago, utility executives worried about markets, deregulation, and the like. Today, as the U.S. electricity system evolves, there are serious grid security issues to confront. Cyberattacks, in particular, have become a top-tier concern and will remain so for the foreseeable future. The attackers only have to get it right once to have devastating effects. The electricity sector has to get it right 100% of the time to avoid them. Other infrastructure threats, such as solar storms or electromagnetic pulses, may also deserve greater attention.

CYBER VULNERABILITIES

Utilities are getting hacked thousands of times a day. There are three kinds of companies: companies that have been hacked and know it, have been hacked and do not know it, and have not been hacked but will be.

The cyberattacks that have occurred have generally come in not through utility SCADA systems but rather through Human Resources departments or elsewhere in corporate systems. Some attackers know how to attack systems beyond those, however; there should be no solace taken in the limits of the attacks that have occurred so far. Cyberattacks are evolving in sophistication. Furthermore, although some plants have segregated their information technology and operational technology systems, others have integrated them, which means cyberattacks that get in through a company's IT system could cause operational disruptions.

There are three kinds of companies: companies that have been hacked and know it, have been hacked and do not know it, and have not been hacked but will be.

It is also possible that cyberattacks on the electricity system could bypass utility networks entirely. Any connectivity in a network is a security vulnerability, but as one moves from ISOs/RTOs down to distribution and individual devices, basic measures to deal with network security get applied less rigorously. Every IoT device deployed is an additional networked interface with the system – and an additional avenue for cyberattacks. The botnet attack in October 2016, which involved baby monitors, affected 164 countries. There are now large numbers of unhardened devices connected to the grid, and since IoT devices have both communications and electricity connectivity, cyberattacks could end up not going through any utility networks at all.

Even measures to enhance grid reliability can simultaneously create additional cyber vulnerabilities. For instance, many data centers would suffer economic losses immediately if the grid went down (which is why some have significant backup generation), but for the grid to provide this level of customer-focused reliability requires the system to respond in seconds or fractions of a second, which means increased automation, which, in turn, can create additional cyber vulnerabilities. Similarly, more visibility is needed into the distribution grid for a variety of reasons, such as maximizing DER effectiveness, enabling IoT, and maintaining grid reliability – but the improved sensing and monitoring involved in getting real-time visibility also creates cyber vulnerabilities. There is no adequate forum in government to deal with these tensions.

CYBERSECURITY INITIATIVES

Years ago, the United States implemented a generation of policies because of the oil embargo, which primarily affected one sector of the economy: transportation. The electricity network now under threat from cyberattacks and other menaces, however, underlies every other lifeline network and economic sector, including transportation, communications, data centers, and provision of water and natural gas. Accordingly, there is a lot more happening to address grid security than some might realize.

The QER recommended amending the Federal Power Act to clarify DOE's authority to ensure it can address two-way flows on the grid and to allow FERC to propose new reliability standards.

The electricity industry is used to dealing with disruptions in the system, whether from earthquakes, weather events, or human action. For instance, the industry has traditionally had regional mutual assistance agreements to provide help in the event of significant disruptions. Superstorm Sandy exposed the fact that mutual assistance could be done better and more efficiently in terms of delivery of people and equipment, which led to a national effort to coordinate groups and to arrange regular drills. The industry is also pursuing efforts to enhance programs to track and share equipment, including transformers. Now, cyberattacks have become an additional threat to plan for and address.

Investor-owned utilities are working closely with each other and with municipal utilities and co-ops on cybersecurity, looking at how best to analyze information, prevent attacks, and respond if an attack is successful. The industry is also coordinating well with the government, sharing information on evolving threats and meeting with major government officials multiple times a year through the Electricity Subsector Coordinating Council (ESCC). The current Administration still appears to be on board with this effort. In addition, the ESCC recently formed a cyber mutual assistance program, in which more than 100 utilities have voluntarily agreed to share their resources – mainly human resources – in the event of an effective cyberattack.

Human resources are a major challenge. The industry is discovering that there are not many qualified, skilled people who know how to implement cybersecurity. There are, however, very good cybersecurity capabilities at some of the national labs, which can work with and build cybersecurity capacity within utilities (paid for out of rate cases). There are also some creative models, though not widespread, of getting top talent from big data companies to come in part-time and help test utility systems. In addition, some cross-sector mutual assistance agreements are starting to be put in place between the electricity sector and sectors that have many more people devoted to cybersecurity, such as banks and telecomm, to share experts for incident response. Interestingly, there are some personnel challenges on the opposite end of the spectrum as well: as the grid becomes more digitized, there is increasing attention being paid to the potential for supplemental operating systems – i.e., being able to operate systems manually if needed in the event of a catastrophic attack or disruption – but most of the workers who ran the old plants in the analog days are retired.

Not investing in cybersecurity can be costly, but investing in it is also costly. It is impossible to get perfect security, so the industry has to make choices about tradeoffs and levels of risk. Some products to help utilities with cybersecurity are starting to come to market, such as software that identifies what is happening in operational technology systems. The industry cannot handle all cyber-defense on its own, though, nor should it. There ought to be a higher federal responsibility, as cybersecurity of the grid is a national security imperative. (At the state level, very few state regulators have security clearance and so do not have a full understanding of the cybersecurity threat; they feel vulnerable, a little uninformed, and yet ultimately responsible.)

The only enforceable federal cybersecurity standards are on the bulk power system. Despite their increasing interdependence, there are no enforceable standards on the gas system, nor are there applicable standards for the distribution system, IoT devices, or other DERs. To fill part of that void, DOE's Office of Electricity has provided great support to distribution utilities, public power, and co-ops to test tools, share information, and promote tabletop exercises on cybersecurity.

Even where the federal standards do apply, no one in the industry thinks compliance with government regulations and standards on cybersecurity are enough to guarantee security. All the different jurisdictions, federal entities, and business models involved make it hard to get rapid and clear responses on cybersecurity issues. Cyber issues do not respect the Federal Power Act jurisdictional structure that draws a bright line between bulk power systems (federal) and distribution systems (state); the Federal Power Act, written in 1935, is completely inadequate for cybersecurity and ought to be revisited. The FAST Act transportation bill that passed in December 2015 included new emergency authorities for the Secretary of Energy over critical electricity infrastructure in the event of a cyber (or other) attack. It also made DOE the sole sector-specific agency for cybersecurity and electricity, though President Trump's May 11 executive order on cybersecurity has made that designation less clear, as it tasked a suite of agencies and entities with jointly assessing the status of grid cybersecurity.

Cybersecurity was one of the key issues the Department of Energy looked at in its Quadrennial Energy Review 1.2, released in January 2017. The QER recommended amending the Federal Power Act to clarify DOE's authority to ensure it can address two-way flows on the grid and to allow FERC to propose new reliability standards. It also recommended permitting the collection of data on security events to inform the President, adopting integrated electricity security planning and standards on a regional basis, assessing the interdependencies of natural gas and electricity system infrastructure for cybersecurity protections, and creating a billion dollar grant program for utilities to modernize substations.

There is also an argument to be made that grid cybersecurity efforts should be included in any federal infrastructure legislation; the grid is public interest infrastructure at least as important as bridges and roads. The Department of Energy also needs more budget to help it organize the industry for emergency response, including regular, robust tabletop exercises. Emergency response is now a serious part of DOE's mission; there may even be a need to formalize an Assistant Secretary for Emergency Response position.

DEEP DECARBONIZATION

There is no going back on a low-carbon future, regardless of current U.S. politics. Other countries, businesses, states, cities, civil society, and others have all made that clear. For instance, many business leaders are not making long-term investments in anything other than a low-carbon future now. The path to that future may well be rockier and a little longer given the current U.S. Administration, but the end point remains the same: deep decarbonization.

GLOBAL PERSPECTIVE

The climate targets set out in the Paris Agreement – aiming to limit warming to well below 2°C and pursuing efforts to limit warming to 1.5°C – help create a "carbon budget" of what greenhouse gases can still be emitted. About a quarter of global emissions are from agriculture, forestry, and other land use; the other 75% of emissions are energy-related. Total annual greenhouse gas emissions are around 54 gigatons (CO2 equivalent), about 40 gigatons of which are CO2 emissions. At that rate, the carbon budget to limit warming to 1.5°C will be used up in 6 years. The scale of decarbonization is much greater and much harder to achieve than many people might recognize. Global emissions have to peak as soon as possible.

At that rate, the carbon budget to limit warming to 1.5°C will be used up in 6 years.

The Paris Agreement was only a first step. The Nationally Determined Contributions (NDCs) submitted in Paris are not nearly enough to achieve deep decarbonization. To remain under 2°C of warming, the International Energy Agency (IEA) projects that additional efforts beyond the NDCs are needed, including addressing upstream methane emissions and fossil fuel subsidy reform. The IEA projects that the largest share of additional reductions will come from energy efficiency, requiring more than $1 trillion of investment in energy efficiency each year globally by 2035. That is a heavy lift, even though getting there would be a net benefit to the economy, with savings exceeding investments; energy efficiency investment in 2016 was only $231 billion.

Technology, innovation, public policy, regulation, demand reduction, market forces, business models, and other factors all have to be interwoven to achieve the ambitious goal of deep decarbonization. What all of those factors will look like in the future remains uncertain. One thing that is certain is that achieving shallow or moderate decarbonization is very different, from a systems perspective, from achieving deep decarbonization. The former, for example, can be achieved with moderate scaling up of renewables and substitution of natural gas for coal. Achieving the latter, however, could require other fuels and technologies that might not be needed to achieve moderate reductions, potentially including hydrogen generated from renewables, nuclear power, and CCS that captures 100% of emissions. There will also be policies needed, including a significant price on carbon.

Industrialized societies have to dramatically reduce greenhouse gas emissions – 80%–90% by mid-century – and deep innovation will likely be needed to reach that kind of goal. While the Paris Agreement is important, Mission

Innovation is therefore also critical. It is important to recognize, though, that there is innovation competition. In other words, clean energy is not the only sector where innovation is occurring; there is also tremendous innovation occurring in, say, the oil and gas sector. Therefore, low-carbon policy will also be essential.

In addition, the oil and gas industry is investing trillions of dollars in bringing more supply online, perhaps because they see deep decarbonization scenarios as highly improbable. More thought is needed about the oil and gas sector's decisions today given the need for deep decarbonization. Currently, policymakers do not have a good analytical way to think about the test they should apply to the permitting of new energy infrastructure given the conflicting realities of what the next 20-30 years will likely look like for oil and gas demand and the need for deep decarbonization.

To achieve deep decarbonization, the electricity system must be front and center, both in terms of making electricity clean and in terms of electrifying other sectors such as industry and transportation. Electrifying other sectors will change the daily load curve and require significant growth in grid capacity (though not beyond the scale of the industry's past growth).

Achieving shallow or moderate decarbonization is very different, from a systems perspective, from achieving deep decarbonization

There is huge potential for transformation in the transportation sector, given the sharing economy, automation, and electrification. Major automakers are devoting large teams and investments to vehicle electrification. EV sales in China were in the hundreds of thousands, and the government is committed to ramping it up. Norway offers huge incentives for EVs, which were 40% of sales last year. Several countries, including India, have made commitments to phase out the sale of gasoline and diesel vehicles within the next couple of decades. It is important, however, to be cognizant of the fact that light-duty vehicles are only responsible for a quarter of oil demand, with the rest coming from trucks, petrochemicals, aviation, and marine. EVs are not going to be nearly enough. In fact, increases in fuel economy are expected to result in far more oil demand reduction than electrification, so on the path to deep decarbonization, improved energy efficiency in transportation needs to be a key focus as well. In addition, it is not clear whether connected, autonomous vehicles would reduce light-duty vehicle energy use or greatly increase it. The result depends on whether increased efficiency outweighs increased demand; of course, if the electricity sector is fully decarbonized, this interplay would not be material for GHG emissions.

It is also important to remember that transitions can happen over the space of a few decades – or faster. They can even be profitable instead of costly. Some argue that deploying energy efficiency and renewable energy at scale and investing some of the energy savings in carbon removal from natural systems could theoretically reach a 1.5°C target while realizing trillions of dollars in energy savings.

THE UNITED STATES

The Paris Agreement invited parties to submit mid-century deep decarbonization strategies by 2020, but the United States, Canada, Mexico, and Germany released theirs early in November 2016. The U.S. strategy set out a vision for cost-effectively reducing economy-wide emissions 80% below 2005 levels by 2050.

Deep decarbonization of the U.S. economy will be very challenging, but it is doable. The U.S. strategy's base projection assumes that CO2 and other greenhouse gases would go up by 2050 without mitigation action, while the U.S. land sink would weaken somewhat, which means the actual reductions that have be made are even greater. The United States would have to reduce emissions from an expected 10 gigatons in 2050 to 1.34 gigatons. If the United States gets rid of the Clean Power Plan and weakens fuel economy standards, both of which had been incorporated into the base case projections, then the base projection for 2050 would be even higher than 10 gigatons, and the volume of reductions needed would increase even more.

The United States cannot afford to wait to take action; 2050 is not that far away. Technological advances and additional policies combined could drive more reductions than the sum of each of them on their own, but the interplay of innovation, policies, and market forces needs to get started soon so there is time for it to play out. A portfolio of technologies is needed, along with mutually reinforcing research, development, and deployment (RD&D), deep innovation, carbon prices, and sector-specific policies.

Anticipated building blocks of deep decarbonization in the United States include energy efficiency (in transportation, buildings, and industry), decarbonization of electricity (including renewables, CCS, and nuclear power), fuel switching (i.e., electrifying a lot of heat and transport), some low-carbon fuels (e.g., hydrogen, biofuels), reductions in non-CO2 emissions (e.g., methane leakage, phasing out hydrofluorocarbons), and enhancement of land sinks and CO2 removal. CCUS may be especially important for deep decarbonization of the industrial sector.

The challenge for CCS may not be cost as much as the inability to finance a plant; there is a need for policies that enable real finance, such as a production tax credit for CCS.

Energy efficiency is the greatest energy resource in the United States and, as is the case globally, a key pillar of deep decarbonization efforts. Energy efficiency and conservation accounted for 61 quads of U.S. energy saved in 2015, resulting in reduced energy-related CO2 emissions and hundreds of billions of dollars of avoided energy costs. Even as the United States has been shaving demand and using less energy, the economy has been growing; the country basically doubled its energy productivity between 1980 and 2012, with an annual rate of improvement of more than 2%. Doubling energy productivity again by 2030 would result in significant energy savings, CO2 emission reductions, and job creation across sectors. The biggest opportunity and challenge is in the transportation sector, which could account for more than half of the energy savings. To achieve another doubling of U.S. energy productivity, though, requires clear price signals, continued and increased federal funding for RD&D, stable and favorable regulatory frameworks at all levels of government, a particular focus on the transportation sector, a move to a systems approach in building efficiency (as opposed to focusing on components such as light bulbs), increased education and outreach, and access to standardized financing mechanisms.

Decarbonization of electricity is another vital building block, not least because the power sector is the easiest sector to decarbonize (though still far from easy). U.S. power sector emissions are already about 25% below 2005 levels, due to factors such as greater energy efficiency, increased deployment of renewables, and fuel switching from coal to natural gas. That reduction trajectory should continue, although the trajectory may depend upon the fate of the existing U.S. nuclear power fleet, which provides about 60% of all carbon-free electricity generation in the country. If those plants close and are replaced by natural gas or coal, power sector emissions would start to rise. On the other hand, there is an argument to be made that keeping distressed nuclear reactors with high operating costs running is not beneficial for the climate, as the money could be reinvested in much cheaper energy efficiency to achieve greater emission reductions. Addressing the long lives of the existing fossil fuel infrastructure may also be needed, given the high levels of future carbon emissions that such infrastructure locks in. A program to buy up excess high-carbon generating facilities – kind of a "cash for clunkers" program for the power sector – could be helpful.

Carbon capture, utilization, and storage (CCUS) will likely be needed as well, both for the power sector and the industrial sector. There will be continuing pressure in the United States to have coal as part of a low-carbon portfolio, and CCS technologies will be needed for that. (While CCS ought to represent an opportunity to get fossil fuels and non-fossil fuels into the same climate discussion, that has not happened in the United States.) Industry has been using CCUS for decades, and the technology works. There are 16 large projects around the world, with more under construction or in planning, but deep decarbonization will likely require 100 times more CCUS projects than current levels. While CCS is often seen as too expensive, gas, coal, and biomass with CCS can be cost competitive with further RD&D and deployment. The challenge for CCS may not be cost as much as the inability to finance a plant; there is a need for policies that enable real finance, such as a production tax credit for CCS. The section 45Q tax credit for CCUS could conceivably be included if there is tax deal at the end of the year, which could help CCS projects become more economic. CCS also has a range of political, legal, and regulatory challenges to overcome; for instance, the scale of underground storage that would be needed for emissions at scale, while enormous, is available, but there are big political, liability, and other issues to contend with. In addition, there is a need for more CO2 infrastructure (e.g., pipelines) in the country. There also is not nearly enough emphasis on real breakthrough CCS technologies, which is largely a governmental role.

Decarbonization outside the power sector is harder, but it can be done. For instance, in the transportation sector, an aggressive U.S. policy push on zero-emission vehicles (which could run on electricity or hydrogen), among other measures, could greatly accelerate vehicle deployment and reduce emissions. Electric vehicles are already starting to deploy faster, though they remain a tiny portion of the fleet – and likely will until around the middle of the next decade, at which point they may reach a tipping point in terms of range, cost, and familiarity.

It may well be impossible to actually decarbonize fast enough to meet climate targets, and there will be some irreducible fraction of emissions that will be incredibly tough to abate, so achieving deep decarbonization also means getting to negative emissions relatively quickly. In other words, in addition to cutting back on or eliminating carbon emissions into the air, there is also a need to take carbon from the air (and the oceans) and either turn it into durable products or restore it to the earth. Carbon removal can be achieved via biological systems or engineered systems. Biological systems include ecosystem restoration, afforestation, biochar, and other efforts to enhance land sinks. These approaches have relatively low up-front capital costs but also generally involve low volumes, and it is unclear how much they reduce emissions and for how long; accounting of net CO2 changes from land use is highly controversial. Engineered systems include direct air capture, enhanced weathering of rocks, and carbon negative materials. These have great certainty about carbon removal but signifcant costs; the engineered solutions can provide an assured, if expensive, climate backstop. Bioenergy with carbon capture and storage (BECCS) combines biological and engineered approaches. Since significant levels of negative emissions may be needed in the near future, the United States needs a much stronger innovation agenda and research program focused on carbon removal.

The policies of the Trump Administration, however, represents a sizable monkey wrench thrown into the already challenging task of achieving deep decarbonization in the United States and around the world. While there are some areas where the announced Trump Administration policies could seed positive things for deep decarbonization, such as support for expanding nuclear power, these have not been backed up by budget requests, and there are many policy efforts attempting to move in a more carbon-intensive direction. For the next few years, cities and states may have to be an even bigger source of decarbonization progress.

Cities in particular can be key players in achieving deep decarbonization, given their population density and energy use. Cities, of course, will not be able to make up fully for the absence of federal leadership, and there are aspects of deep decarbonization they would be hard-pressed to influence. For instance, industry and agriculture tend not to be located in cities, and those account for about half of greenhouse gas emissions. In addition, many of the policy interventions needed to address city emissions – such as emissions from vehicles and electricity – are done at the federal and state levels, not at the city level. Nevertheless, cities have many opportunities to address decarbonization. Local governments can, among other things, push buildings to electrify heating, more broadly address energy use through building codes, buy EV fleets, promote EV charging networks, and support efforts to boost public transportation. The digitalization of sectors also tends to drive towards customization, so it is certainly possible that more controls will be added to the local government toolbox over time.

CHINA AND OTHER DEVELOPING ECONOMIES

While U.S. decarbonization actions are critical, the developing world's development pattern will materially determine the course of climate change. Although nuclear power is struggling in the United States, much of the rest of the world remains very interested in it; in China, India, Abu Dhabi, Jordan, Hungary, the Czech Republic, Turkey, Vietnam, and elsewhere, governments are pursuing new nuclear power plants. On the other hand, the rest of the world is still burning coal, even if the United States ramps down its use of coal for power generation. There are also still lots of people in the world with no access to electricity. To achieve the 2°C goal, developing countries will have to avoid locking in high-carbon infrastructure; locked-in emissions from existing infrastructure alone is already close to the carbon budget, so premature retirement of a great deal of existing infrastructure may be necessary. The developing world must pursue low-carbon infrastructure pathways (which might require additional international financing support).

China's development pathway, in particular, could shape the future of climate change. China's booming growth – including lifting most of its population out of poverty – required a great deal of energy, which in turn resulted in a great deal of greenhouse gas emissions. The growth also came at the cost of extreme air pollution, mainly caused by coal combustion in power generation and industry, though vehicle emissions also played a role. China, in 2016, emitted more greenhouse gases than the United States and the European Union combined. Emissions from fossil fuel combustion tripled between 2000 and 2012, but they leveled off around 2014 (though there is some uncertainty about the data). China is responsible for more than a quarter of annual global CO2 emissions from fossil fuel combustion (about 27%), far ahead of the United States (about 16%). China clearly must play a central role in any deep decarbonization effort, although it is important to put its emissions in context. Annual emissions are not the only framing. Looking at cumulative emissions over the past century, for example, China (about 12%) is far behind Europe (about 33%) and the United States (about 26%). Looking at per capita emissions, the United States (16.4 tons per capita) again is far ahead of China (7.6 tons), though China is now ahead of Europe (6.7 tons).

China, in 2016, emitted more greenhouse gases than the United States and the European Union combined.

China is aware of the role it can play and has adopted a number of climate goals and policies. It has committed to peak its CO2 emissions around 2030, making its best efforts to peak earlier; this is a conservative goal, as emissions could peak around 2025, but there remains uncertainty about how high the peak will be. China also has a nationwide emissions trading program launching in 2017, building on the pilots in seven provinces that have been running for the past few years. In addition, China is placing limits on coal, investing heavily in renewable energy and energy efficiency, and looking to expand its nuclear power production.

Although China has no long-term deep decarbonization goal, there have been some important research reports laying out pathways for achieving 50% reductions by 2050. There are reasons, however, to be pessimistic about the prospects for deep decarbonization in China. China still has very heavy coal dependence. The industrial sector, which dominates the Chinese economy, is responsible for between 45% and 60% of emissions and is a challenging sector in which to achieve emission reductions. The massive urbanization occurring in China – one of the biggest migrations in human history – means more construction and consumption. On the other hand, there are reasons for optimism as well. In contrast to the United States, China has great capacity for long-term planning, a commitment to a price on carbon, broad support for a low-carbon economy, and high awareness of climate impacts. Its economy is also shifting long-term towards being less energy-intensive, and the country has good low-carbon resources. China's innovation culture is a bit of an unknown in the deep decarbonization equation; innovation is not really part of Chinese culture now, but China is trying to infuse more innovation into the country and is aggressively encouraging Chinese PhDs to return home from the United States.

NORTH AMERICAN ENERGY INTEGRATION

The developments in U.S. energy over the past few years have occurred during a period of increased energy integration among the three North American countries, both bilaterally and trilaterally. Bilateral energy linkages have been growing between the United States and its northern and southern neighbors. Trilateral energy discussions in North America were rejuvenated in 2014 after a multi-year lull, and – so far – they have survived changes of the party in power in the three countries.

CANADA-U.S. INTEGRATION

U.S. energy integration with Canada has been strong for a long time. The first-ever international electricity crossing was in Niagara Falls in 1901, and now there are more than 30 transmission lines between the two countries. All major U.S.-Canada transmission projects are near their capacity levels, so if the relationship is to grow, there is a need to grow the infrastructure. Additional cross-border transmission lines are envisioned, including a concept between Minnesota and Manitoba that would have Manitoba hydro serving as storage for North Dakota wind. One aspect of the heightening of the U.S.-Canada relationship in 2014 was a Memorandum of Understanding (MoU) to conduct side-by-side reviews of the processes for cross-border transmission infrastructure permitting.

U.S. energy integration with Canada has been strong for a long time.

Canada and the United States have a symbiotic network, building on each country's respective strengths and attributes, including seasonal differences in demand. Electricity demand in Canada spikes in the winter due to demand for space heating, whereas demand in the United States spikes in the summer due to demand for air conditioning. British Columbia also provides reliability to the Pacific Northwest, in part because Canada, in contrast to the United States, is investing in its hydro resources. In addition, the countries work together on grid security and resilience, with the August 2003 blackout serving as a major turning point in recognizing the shared threats when countries share infrastructure. Following Superstorm Sandy, for instance, Canadian utilities sent hundreds of employees to the United States to help with the recovery. In 2016, President Obama and Prime Minister Trudeau announced a statement on climate and clean energy leadership that included a joint strategy on grid security, which was released in December 2016. Mexico has also been working with NERC increasingly on security and reliability issues.

The relationship is not without its points of contention, however. For instance, only three U.S. states – Minnesota, Vermont, and Wisconsin – accept Canadian hydro explicitly in their Renewable Portfolio Standards (RPSs). That is a bottleneck the Canadians would like to overcome. Some states, such as Massachusetts, seem to have a preference for state-produced renewables over Canadian hydro.

MEXICO-U.S. INTEGRATION

It was Mexico's historic energy sector reforms that spurred consideration of increased bilateral and trilateral engagement. Mexico started becoming more similar to the United States and Canada in terms of oil and gas contracts, electricity markets, and regulation. Mexico's electricity law, for instance, looked at some of the best international models, including some elements in the United States (e.g., from CAISO and ERCOT). Mexico now has a set of market rules that many U.S. companies find comfortable, and the country has started deploying market mechanisms such as spot markets, capacity markets, and auctions for clean energy certificates (which have produced some of the lowest prices for renewable energy in the world). Mexico still has a lot of room to grow, and its mechanisms do not yet have a lot of depth, but the signs are what one would expect in a nascent market that has the right elements to provide reliable, inexpensive electricity.

Mexico has a much smaller energy relationship with the United States than Canada does. Electricity connections are much larger on the northern U.S. border than on the southern, partly due to history and partly due to where the countries' populations are located. There are 11 cross-border interconnections between the U.S. and Mexican electricity systems, with 2 more planned. Energy integration on the southern border has been mostly about natural gas moving south. However, the growing importance of Texas in the U.S. energy world, and its expected population growth over the next few decades, argues strongly for increased integration.

Mexico and the United States also work together on reliability and cybersecurity, including a 2017 MoU between the two countries on these issues. The MoU builds on previous collaborations on reliability and cybersecurity, including a North American Electric Reliability Corporation (NERC) assessment of Mexican vulnerabilities to cyberattack that is now the basis of action and investment to boost Mexican cyber-resilience and defenses. Mexico also helped keep the lights on in Texas when the state had some significant operational problems.

In addition to advancing integration with the United States, Mexico is also exploring ways to better connect Mexican electricity to the rest of Central America, though there are some complicated political issues that present obstacles.

CLIMATE CHANGE & CLEAN ENERGY

The June 2016 trilateral meeting of North American leaders produced agreement on a goal of 50% clean energy (defined broadly) across the continent by 2025. The countries also agreed in 2016 to develop a North American Renewable Energy Integration Study, which will culminate in 2019 and will seek to develop consistent data sets for modeling the impacts of renewable energy integration.

In terms of clean electricity, Canada is already at 80% (Hydro, Nuclear energy, and renewables) and hopes to grow its portion to help the United States and Mexico. Canadian hydro is already well-linked to the United States. Mexico, meanwhile, introduced a clean energy portfolio standard – with a broad definition that includes nuclear power, hydro, solar, and wind – and has an internal clean energy target of 35% by 2024, in addition to the North American commitment. Due to its long-term auctions, solar and wind constitute a growing share of Mexican energy. Mexico is having discussions with California Governor Jerry Brown about whether Mexican clean energy certificates could be used in California for RPS compliance. Mexico is also constructing transmission lines to connect its renewables-rich regions to its national system and to the United States.

With regard to climate change specifically, Canada and Mexico are both taking action as well. Canada will institute a carbon price floor across the economy that starts at $10 in 2018 and increases by $10 every year until 2022, when it will reach $50; provinces can go beyond that floor if they so desire. Canadian provinces are also linking up with U.S. carbon pricing initiatives; Quebec and Ontario are formally linking to California's cap-and-trade system, while the Eastern Provinces are coordinating with New England and the RGGI states. Mexico too has made climate commitments and is making good progress in reducing emissions. In the power sector, natural gas is replacing fuel oil as the main fuel, which, coupled with the growth in renewable generation, is leading to a big drop in emissions, though Mexico still has a great deal of untapped energy efficiency opportunity. Natural gas and electricity are also making inroads in the transportation sector, and there is progress being made in addressing agricultural emissions too.

Given the political changes in the United States, it is unclear what will happen to trilateral commitments that do not fit with the Trump Administration's policy, such as the 50% clean energy target. It is possible that market developments will drag the continent towards that target anyway, and Canada and Mexico will also likely engage more directly in bilaterals with U.S. states. The trilateral relationship may be more fruitful for the next few years on common ground such as CCS and security.

POTENTIAL ROADBLOCKS TO NORTH AMERICAN INTEGRATION

While the regional integration seen in past years may continue under the Trump Administration, it also may not. There are reasons for skepticism.

The two U.S. borders are very different, not only in terms of the energy flows noted earlier, but also in terms of trade deficits. President Trump has a history of looking at issues across borders in terms of bilateral trade deficits. One of the policy views he has consistently held over the years is that trade deficits are the result of bad deals and bad behavior by trading partners. He has asked for a trade deficit review all around the world, which could create a target list for his Administration to go after in adjusting trade and renegotiating agreements.

Canada and Mexico are both huge trading relationships for the United States (ranking first and third, respectively). The U.S.-Canada trade deficit is essentially a wash, with about a $12 billion deficit in goods and a $24 billion surplus in services (from the U.S. perspective), though that still has not stopped President Trump from restarting some trade tensions with Canada. With Mexico, on the other hand, there is a $56 billion deficit; looking only at goods, the deficit rises above $60 billion, though the United States has a surplus with Mexico in terms of energy. President Trump may not feel he has readjusted the U.S. relationship with Mexico appropriately unless the trade deficit disappears. The main ways to do that are tariffs, quotas, and managed trade, and Canada and Mexico will not agree to any of those.

Another policy view that President Trump has varied little on over the years is that immigration is bad for the United States. In addition to trade tensions and the prospect of North American Free Trade Agreement (NAFTA) renegotiations, Mexico therefore also has to confront the additional tensions from the Trump Administration's fixation on building a wall on the southern border and conducting mass deportations of Mexicans, which are sensitive issues in Mexico. Trump's actions and rhetoric could strengthen the hand of an anti-U.S. candidate in next summer's Mexican elections and potentially undermine Mexican energy reforms, straining U.S.-Mexico relations.

Growing Mexican reliance on U.S. natural gas is also part of the political discussion in the next Mexican election. There are reasons to think the United States will not wield that dependence against Mexico, as the gas coming out of the Permian needs a market, but Mexico is conscious of the vulnerability. In the short-term, imports from the United States may increase, but longer-term, Mexico is increasing its regasification terminals and is targeting oil and gas contracts where it thinks it has its own significant natural gas reserves.

There are thus two visions of North America that could emerge under this Administration. One is the integrated version, albeit with less emphasis on areas involving climate change and clean energy. The other is a version with thickened borders, a renegotiated NAFTA, and trade disputes. Which vision will win out is rather unclear. The U.S. energy surplus with Mexico makes it perhaps more likely that at least energy integration will continue. Energy interests in the United States have also been supporting NAFTA, recognizing that framing the entire North American relationship in terms of trade deficits misses a great deal of regional potential and could hurt the United States. (Even these interests, though, are trying to adjust to the new Administration and are focusing on taxes and regulations more than on trade.) In addition, it is very unlikely that Congress will vote on NAFTA by the end of the year, if ever; most in Congress do not want a vote on the record on this issue. So the question becomes what the White House can do on its own, in the face of pressure from some businesses not to mess up the North American trading relationship. It is possible Trump will seek a victory narrative that does not actually change that much. Furthermore, there have been some good signals from the Administration, including Sec. Perry's visit to Mexico and Sec. Ross calling energy deficits "blameless". All that being said, however, the main drivers of action right now are in the White House and nowhere else. These will be crucible moments between national interest and nationalist rhetoric.

Along those lines, it is important for the industry to focus on the fact that there will be four new commissioners at FERC – the first time that has happened since the early 1990s. FERC has exclusive jurisdiction over interstate pipelines, the infrastructure needed to export natural gas, the interstate transmission grid, and wholesale electricity sales in the United States. Those concerned about obstacles to continued North American integration should weigh in at FERC at this time of commissioner turnover to remain welcoming to markets, imports, and exports.

APPENDICES: AGENDA

SATURDAY, JULY 15

Opening Session — **Introduction**

David Monsma, Executive Director, Energy and Environment Program, The Aspen Institute

Welcome

Ernest Moniz, Professor, MIT;
Former US Secretary of Energy

Anne Pramaggiore, President & CEO, ComEd

SESSION I: **Electricity Distribution System – Implication of Technology on Policy and Policy on Technology**

A two-way, interactive, electric distribution system needs a combination of new technology, regulatory structure, appropriate rate making mechanisms, and security features to be successful and bring economic value and a clean energy future to the hundreds of millions of customers it services. What is the role of technology innovation in the smart grid, the value of distributed generation, and how does demand response and load shaping impact it?

Moderator: Anne Pramaggiore

Discussants:

Peter Fox-Penner, Director, Institute for Sustainable Energy, Boston University
Sue Tierney, Senior Advisor, Analysis Group
Jeffrey Taft, Chief Architect for Electric Grid Transformation, PNNL
Kim Greene, Executive Vice President & COO, Southern Company

SESSION II: **Bulk Power and the Future of Baseload Generation**

While periodically adjusted, current electricity market structures were designed for a 20th century electricity system. New technologies, business models, and consumer demands raise concerns about the relevance of these designs in the 21st century electricity marketplace. What is adequate and what are the risks of current electricity market structures in the context of market trends? How do new technologies and business models impact reliability? How does the need for or lack of need for baseload generation with high capacity factors impact long term planning?

Moderator: Ernest Moniz

Discussants:

Joseph Hezir, Principal, Energy Futures Initiative
Paul Chodak, Executive Vice President, Utilities, AEP
Cheryl LaFleur, Acting Chairman, FERC
James Bushnell, Professor, Department of Economics, UC Davis

SUNDAY, JULY 16

SESSION III: **Deep Decarbonization**

To reach deep decarbonization goals, in addition to scaling up clean energy technologies, improvement must be made in the electrification of buildings, some industry, and transportation, as well as improved efficiency. What are the pathways to get to deep decarbonization and what technologies and policies are needed?

Moderator: Ernest Moniz

Discussants:

Judi Greenwald, Principal, Greenwald Consulting
Kateri Callahan, President, Alliance to Save Energy
Julio Friedmann, Senior Advisor, Lawrence Livermore National Laboratory
David Sandalow, Inaugural Fellow, Center on Global Energy Policy, Columbia University

SESSION IV: **Rapidly Changing Electricity System and Technology-Enabled Value Creation – The Internet of Things and Transportation**

The electricity system is changing rapidly. Two key areas that enable value creation for both the utility and the consumer are the Internet of Things (IoT) and transportation. What are the ways in which new technology add value to the system and what policies would help to enable this?

Moderator: Anne Pramaggiore

Discussants:

Hannah Bascom, Head of Regulated Energy Partnerships, Nest Labs
Tim Healy, Chairman & CEO, EnerNOC
Jan Vrins, Managing Director, Global Energy Practice Leader, Navigant
Bob Rowe, President & CEO, NorthWestern Energy

SESSION V: **National Security and Cyber Security – The Role of the Electricity Sector and Regulatory Implications**

Without access to reliable electricity, much of the economy and all electricity-enabled critical infrastructures are at risk. These infrastructures include our national security and homeland defense networks, which depend on electricity to carry out their missions to ensure the safety and prosperity of the American people. What are the cyber and physical issues with regard to the grid and how can utilities prepare?

Moderator: Clint Vince, Chair, Global Energy Sector, Dentons US

Discussants:

Melanie Kenderdine, Principal, Energy Futures Initiative & EJM Associates
Philip Moeller, Executive Vice President, Business Operations Group and Regulatory Affairs, Edison Electric Institute

MONDAY, JULY 17

SESSION VI: **North America – Grid Security and Integration**

Historically, integration of the power systems of Canada, Mexico, and the US occurred by gradual, ad hoc, and regional adjustments implemented by an array of regional, public, and private stakeholders, reflecting the complex and fragmented jurisdictions in all countries. How will this collaboration on electricity and natural gas occur in the future? What are the other ways the countries can work together to enable a more secure grid?

Moderator: Ernest Moniz

Discussants:

César Emiliano Hernández Ochoa, Deputy Secretary of Energy for Electricity, Ministry of Energy of Mexico
Drew Leyburne, Director General, Strategic Policy, Department of Natural Resources of Canada
Nelson Cunningham, President & Co-founder, McLarty Associates

PARTICIPANTS

Anne Slaughter Andrew, Board Chair, TerViva

Shay Bahramirad, Director of Distribution System Planning, Smart Grid & Innovation, ComEd

Beth Bartholomew, Principal Director, Smart Grid Services, Accenture

Lisa Barton, Executive Vice President, AEP Transmission; President & COO, AEP Transmission Holding Company

Hannah Bascom, Head of Regulated Energy Partnerships, Nest Labs

Angela Becker-Dippmann, Democratic Staff Director, Senate Committee on Energy and Natural Resources

Roger Berliner, Council President, Montgomery County Council

Aaron Berndt, Head of West Coast Energy Partnerships, Nest Labs

Jason Bordoff, Professor & Founding Director, Center on Global Energy Policy, Columbia University

Sam Brothwell, Senior Analyst, Energy Income Partners LLC

Nora Mead Brownell, Co-Founder, ESPY Energy Solutions, LLC

James Bushnell, Professor, Department of Economics, University of California, Davis

Sandra Byrd, Vice President, Public Affairs and Member Services, Electric Cooperatives of Arkansas

Kateri Callahan, President, Alliance to Save Energy

Paul Chodak, Executive Vice President, Utilities, American Electric Power

Karin Corfee, Managing Director, Navigant Consulting, Inc.

Nelson Cunningham, President & Co-founder, McLarty Associates

Thomas Edgar, Director & Professor, Energy Institute, The University of Texas at Austin

Shelley Fidler, Principal, Governmental Affairs, Energy & Environmental Policy, Van Ness Feldman

Emily Fisher, Vice President, Law, Edison Electric Institute

Peter Fox-Penner, Director, Institute for Sustainable Energy, Boston University

Julio Friedmann, Senior Advisor, Lawrence Livermore National Laboratory

Jeffrey Gleeson, Product Manager, Energy Services, Nest Labs

Paula Gold-Williams, President & CEO, CPS Energy

Sekita Grant, Policy and Impact Strategy Manager, Emerson Elemental

Kim Greene, Executive Vice President & COO, Southern Company

Judi Greenwald, Principal, Greenwald Consulting

Dave Grossman, Principal, Green Light Group (*Rapporteur*)

Jason Grumet, President, Bipartisan Policy Center

Jeff Guldner, Executive Vice President, Public Policy, Arizona Public Service Company; General Counsel, APS and Pinnacle West Capital Corporation

Julia Hamm, President & CEO, Smart Electric Power Alliance

Emma Hand, Partner, Dentons LLP

Dede Hapner, Vice President, FERC and ISO Relations, Pacific Gas and Electric Company

Tim Healy, Chairman & CEO, EnerNOC

Stu Hemphill, Senior Vice President, Customer and Operational Services, Southern California Edison

César Emiliano Hernández Ochoa, Deputy Secretary of Energy for Electricity, Ministry of Energy of Mexico

Joseph Hezir, Principal, Energy Futures Initiative

Barbara Humpton, President & CEO, Siemens Government Technologies

Lady Barbara Judge, CBE, Former Chairman, U.K. Atomic Energy Authority; Member, Strategic Advisory Council, Statoil ASA

Sue Kelly, President & CEO, American Public Power Association

Melanie Kenderdine, Principal, Energy Futures Initiative & EJM Associates; Non-resident Senior Fellow, The Atlantic Council

Jinmi Kim, Special Assistant to IPCC Chair, Intergovernmental Panel on Climate Change, Korea University

Cheryl LaFleur, Acting Chairman, Federal Energy Regulatory Commission

Hoesung Lee, Chair, Intergovernmental Panel on Climate Change

Stéphane Lessard, Consul of Canada in Denver, Government of Canada

Drew Leyburne, Director General, Strategic Policy, Department of Natural Resources of Canada

Amory Lovins, Chief Scientist, Rocky Mountain Institute

Bill Massey, Senior Counsel, Covington & Burling LLP

Lourdes Melgar, Robert E. Wilhelm Fellow, Center for International Studies, MIT

Philip Moeller, Executive Vice President, Business Operations Group and Regulatory Affairs, Edison Electric Institute

Bill Mohl, Executive Advisor, WMM Enterprises

Ernest Moniz, Professor, MIT; Former US Secretary of Energy (*Co-Chair*)

David Monsma, Executive Director, Energy and Environment Program, The Aspen Institute (*Moderator*)

Sharelynn Moore, Vice President, Global Marketing and Public Affairs, Itron, Inc.

Jay Morrison, Vice President, Regulatory Issues, National Rural Electric Cooperative Association

Philip Nevels, Director, Utility of the Future, ComEd

Richard Newell, President & CEO, Resources for the Future

Bob Perciasepe, President, C2ES

Lara Pierpoint, Senior Fundamental Program Strategy Manager, Exelon

Maria Pope, Senior Vice President, Power Supply, Operations and Resource Strategy, Portland General Electric Co.

Anne Pramaggiore, President & CEO, ComEd (*Co-Chair*)

Gil Quiniones, President & CEO, New York Power Authority

James Rogers, Former CEO, Duke Energy

Robert Rowe, President & CEO, NorthWestern Energy

Gwen Ruta, Senior Vice President, Climate & Energy, Environmental Defense Fund

David Sandalow, Inaugural Fellow, Center on Global Energy Policy, Columbia University

Jan Schori, Trustee, North American Electric Reliability Corporation

Justin Segall, President & Founder, Simple Energy

John Shelk, President & CEO, Electric Power Supply Association

Charif Souki, Chairman of the Board, Tellurian Inc.

James Spiers, Vice President, Business and Technology Strategies, National Rural Electric Cooperative Association

Jeffrey Taft, Chief Architect, Electric Grid Transformation, Pacific Northwest National Laboratory

Sue Tierney, Senior Advisor, Analysis Group

Clint Vince, Chair, Global Energy Sector, Dentons US LLP

Jan Vrins, Managing Director, Global Energy Practice Leader, Navigant Consulting, Inc.

Karen Wayland, Executive Director, Clean Energy Project

Michael Webber, Deputy Director & Professor, Energy Institute, The University of Texas at Austin

Martin Wilhelm, Managing Partner, Geopolis Energy Partners

Lisa Wood, Vice President, The Edison Foundation; Executive Director, Institute for Electric Innovation

Jacob Worenklein, Chairman & CEO, US Grid Company

ASPEN INSTITUTE STAFF:

Nikki DeVignes, Program Manager, Energy and Environment Program, The Aspen Institute

Greg Gershuny, Managing Director & James E. Rogers Energy Fellow, Energy and Environment Program, The Aspen Institute

Calli Obern, Program Coordinator, Energy and Environment Program, The Aspen Institute

WE WOULD LIKE TO THANK THE GENEROSITY OF OUR SPONSORS:

ComEd®
An Exelon Company

nest®

AEP AMERICAN® ELECTRIC POWER

Sempra Energy®

TELLURIAN

DENTONS

Itron

NAVIGANT

EEI Edison Electric Institute

Van Ness Feldman LLP

The Edison Foundation
INSTITUTE for ELECTRIC INNOVATION

NRECA International Ltd.
Your Touchstone Energy® Partner

Electric Cooperatives of Arkansas
We Are Arkansas

NorthWestern Energy

energy institute
THE UNIVERSITY OF TEXAS AT AUSTIN