2017 Aspen Institute Clean Energy Innovation Forum

Disruption and Destination:

Clean Energy Innovation, Market Disruption, & Deep Decarbonization

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THE ASPEN INSTITUTE ENERGY & ENVIRONMENT PROGRAM

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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.

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Co-Chairs Forward

Our goal with the Aspen Institute's Clean Energy Innovation Forum is always to take critical stock of the present and to then drive a dialogue that can forecast – and even shape – the future of the energy sector. Over the [six] years of the Forum, we have consistently looked back to find that our forecasts of change have proven largely prescient.

Our 2017 Forum can perhaps be summed up best with two words: *disruption* and *destination.* At what we believe to be an unprecedented scale, we are witnessing disruption from both within and without the energy sector. Cheap natural gas, plummeting renewable energy costs, and the arrival of economic energy storage are driving fundamental change to energy markets across the oil and gas, electricity, and transportation sectors. And a wide range of forces from beyond the energy sector itself are driving change within it. Digitization, data analytics, corporate sustainability commitments, and evolving consumer expectations of transparency and control of more and more facets of their lives are all putting pressure on our legacy system. *Disruption* seems to be a fair and timely word to describe the state of the energy sector.

Our 2017 Forum can perhaps be summed up best with two words: disruption and *destination.*

As Co-Chairs we seek to stimulate discussion and elicit a wide-range of viewpoints from our participants. But we do not attempt to drive to a particular outcome. Nonetheless, the wide array of participants – utility executives, NGOs, academics, financiers, large corporates, and government officials – seemed to all agree that the future of energy lies in significant, or "deep", decarbonization. This became the clear *destination.* Some see deep carbonization as an inevitable result of the changing of technologies, economics, and customer preference. Others look at deep decarbonization as an environmental imperative for society that must be aggressively supported through public policy. Those differences, however, paled next to the consensus that this is our destination.

Much work remains to be done to understand and harness disruption along the path to a decarbonized energy future that will serve economic and social needs. We will continue to undertake some of that work through the Aspen Institute and working with the remarkable collection of leaders we had the privilege of hosting this summer.

Roger Ballentine and Jim Connaughton

Executive Summary

"Clean energy" is difficult to define, but certainly includes: renewable and other low or zero carbon generation; devices, software, and systems that reduce energy use; and lower carbon transportation technologies. But by any definition, clean energy deployment around the world continues to grow. The cost of renewable energy has been plummeting and is competing and winning contracts as the lowest-cost source of generation in many instances. Virtually throughout the entire world, renewable energy is the fastest growing source of new generation. Along with natural gas, renewables have dominated the new generation marketplace in the United States. In most advanced economies, power demand is flattening in a way that does not necessarily fully reflect economic productivity. The decoupling of energy use from economic growth can be attributed in significant part to the increased use of more efficient devices, processes, and energy systems.

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Decarbonizing transportation is more of a challenge, as it remains the sector most reliant on fossil fuels. Electrification of light-duty vehicles is gaining momentum, as the precipitous drop in lithium-ion battery prices has resulted in greater cost-competitiveness for these vehicles. The number, quality, and variety of electric vehicles (EVs) that will be available over the next few years will help drive the transition, as will a range of other factors, including pledges by automakers and countries to start selling only electric vehicles, interest by utilities in advancing a potential new source of load, and new battery chemistries and designs. Hydrogen fuel cell vehicles, only recently seen as falling out of favor, may be poised to contribute to the transformation of mobility as several major automakers have reasserted their commitment to bringing these vehicles to market. Driven by the efforts of large fleet owners and OEMs, heavy-duty vehicles have become significantly more efficient in recent years. Beyond efficiency, other options for heavy duty vehicles include electrification, hybridization, and low-carbon fuels, though constraints related to cost, scalability, and vehicle duty cycles remain.

Distributed energy resources (DERs) – which encompass a broad and transformational set of technologies that are gaining momentum and that excel at enabling flexible loads – are upending retail markets and the distribution system. DERs can provide significant benefits not just to the customers who use them, but also to utilities and the grid. However, in the face of persistent legacy regulatory structures and utility business models, they also represent real revenue erosion potential for utilities, and require changing approaches to how the grid is managed for economic optimization and reliability. Still, DERs offer the opportunity for a more distributed and dynamic grid architecture, although that is not yet a reality. Big customers – who have the economic heft and whose need for electricity, resilience, and security is the highest from a business point of view – are among the main drivers of DER deployment. Demand has been quite strong from corporate buyers looking both to directly purchase renewables (mostly in deregulated markets) and to leave retail rates (given the widening gap between retail and wholesale prices). Community choice aggregation programs, which could be thought of as the average person's opportunity for choice, are also growing. State and federal policies will be a key ingredient in further broadening DER adoption, including policies on rates, interconnection, financing, procurement, billing, taxes, and trade.

Disruption is not just happening at the retail electricity market level. The changing nature of the U.S. generation mix and state efforts to favor certain generation resources are creating disruptions in wholesale markets. Some older plants (e.g., coal, nuclear) are at the stage of making decisions about retiring or retrofitting, whereas almost everything new being built in the United States is wind, solar, and natural gas. The changes in generation have led to debates about the effect of renewables on baseload resources and on the reliability of the grid, though it seems clear that the influx of renewable energy is not causing problems for grid reliability and management. Nevertheless, where organized wholesale markets exist, wholesale prices continue to plummet because of low natural gas prices, zero-marginal-cost renewables, and stagnant demand. Gas tends to set the marginal price while zero-fuel-cost renewables pull wholesale prices down – a combination that can undermine market support for other types of generation and leading to political backlash and out-of-market solutions.

Because these largely market dynamics negatively impact some assets, there appears to be a growing crisis of faith in competition. That said, market design is rarely meant to be static, and there are several ways markets could be reformed to value additional important attributes (e.g., capacity availability, zero-carbon generation). At some point, the Federal Energy Regulatory Commission will have to weigh in on how state policies are affecting interstate wholesale markets, and the presence of new commissioners represents an opportunity for engagement and education on ways of improving competitive markets.

A portfolio of technologies will be needed across all sectors, including in the areas of energy efficiency, end-use electrification, zero-carbon energy supply, enabling infrastructure, and negative emissions.

Despite all the progress made in clean energy, deep decarbonization is rapidly becoming an organizing principle that guides the evolution of energy systems. Climate impacts are being experienced today, and a lot of warming is already locked in, so serious efforts are needed to reduce greenhouse gas emissions in order to meet the globally accepted target of 80% reductions in emissions by 2050 in every developed nation and 50% in every major developing nation. The power sector will be responsible for a sizable portion of those reductions, but care must be taken to avoid siren song pathways that dead end or that delay achievement of deep decarbonization. A portfolio of technologies will be needed across all sectors, including in the areas of energy efficiency, end-use electrification, zero-carbon energy supply, enabling infrastructure, and negative emissions. It is in our best interests to keep all solution options on the table, including both existing technologies and new advanced technologies.

Without question, achieving such deep emission reductions will require policy action. There is already a scattershot suite of policies and supports for carbon abatement in the United States, but prospects for an increasing, transparent price on carbon – or other big ideas on climate – are hindered by dogma and ideology at the federal level. There is likely no path to deep decarbonization that does not involve some agreement from both sides of the aisle, so progress may need to be tied to bipartisan goals such as resilience or innovation. Advocates of climate action have to do a better job of reaching out to affected stakeholders to bring them on board the decarbonization transition. While deep decarbonization will not be achieved without the U.S. federal government taking a different tack than it is now, states, communities, and private sector actors are beginning to drive the climate conversation, setting their own climate goals and plans across geographies and ideologies. The United States cannot and is not acting alone, though, and a key question regarding deep decarbonization is whether scaled-up clean technologies will find a major role in Asia, Africa, and the Middle East. China has become, in some ways, a new global leader on decarbonization, though there are reasons to be concerned about how real that leadership is. What is happening in China provides all the more reason for the United States to do its part on the climate issue, focus on its innovation advantages, and become the leading exporter of clean technologies to the world.

Status of Clean Energy

While global clean energy investment has been relatively flat (or declining), clean energy costs have declined rapidly, and deployed capacity has continued to grow.

Global Data

For the past several years, new investment globally in renewable energy, biofuels, and smart energy technologies has stayed relatively steady at around $300 billion a year, more or less. Asia, especially China, has become a huge part of the global clean energy investment story over the past decade, now accounting for about half of global investment. While the quality of the data about China can always be questioned, the actual levels of Chinese clean energy investment, installation, and deployment have been consistently impressive.

New global investment actually fell from $349 billion to $287 billion from 2015 to 2016 – a decline of 17% – and Asia was a big part of the reason for that too, as investments by China, Japan, and others dropped. China, for instance, curtailed its clean energy subsidies in recognition of overbuild in wind and solar. More broadly, while the early story for clean energy globally was about strong subsidies creating markets that would collapse once subsidies were reduced, wind and solar are now getting built mostly through auctions for lowest-cost contracts. The cost of renewable energy has been plummeting – solar and wind costs are close to even now – and renewable energy has been competing and winning contracts around the world as the lowest-cost source of generation. The prices have sometimes been remarkably low, such as the 2016 tender in Chile for delivery of solar for less than $30/MWh.

The way money gets raised in the clean energy industry is still very immature, though things are improving. Clean energy developers are basically in the math and risk business; everything has to be financed, and capital cost and availability drive investment. The magic trick in the renewables industry is to make all the complex things the industry does look like a bond, as there is nearly infinite capital for structured, low-risk, long-duration investments. Currently, green bonds are at about $123 billion, up from $15 billion in 2013. A note of caution about green bonds, however, is that there are no real standards for them; there are a lot of self-made claims, and a crisis may be coming when someone calls out a green bond project that is not really green.

> Global cumulative installed power capacity is projected to become much cleaner by 2040.

Despite the drop in global investment, new installed clean energy capacity rose 9% from 2015 to 2016; as clean energy gets cheaper, more can be installed for less money. Over the long term, global cumulative installed power capacity (which is expected to double between 2016 and 2040) is projected to become much cleaner, with coal's share dropping from 30% to 13%, while utility-scale solar grows from 3% to 22%. It is important to note, however, that increasing capacity does not precisely correlate to increasing generation; while wind and solar capacity factors have been rising, there will be more flexible capacity resources such as batteries and demand response in a more variable grid, so while capacity growth will go way up, generation growth will increase more slowly. In addition, the actual amount of coal generation will not actually decline all that much, as the overall capacity pie will get bigger. This highlights the fact that even this projected cleaner suite of power capacity resources gets humanity nowhere near a 2°C climate target; a lot more needs to happen to carbon-optimize the future power system.

U.S. Data

The United States has mirrored some of the global trends on clean energy, in addition to seeing an increased role for natural gas. From 2007 to 2016, the U.S. primary energy supply has experienced substantial shifts, with renewables growing from about 6.5% to 10.4% and natural gas growing from 23.5% to 29.6%. Just looking at electricity, renewables grew from 8% to 16%, while natural gas grew from 22% to 34%; natural gas is now the driver of power prices in almost every U.S. market. Over that same time period, U.S. GDP grew while total energy use fell; greater energy efficiency has improved the country’s energy productivity.

> US renewable generation has grown from 6.5% to 10.4% in the last decade.

Clearly, levels of renewable energy penetration are starting to become significant, with some of the highest rates in California, Idaho, Maine, and elsewhere. While renewables penetration in the deep South is still lagging, overall penetration rates have become meaningful. Wind costs have dropped significantly over the past few decades and have been below 10 cents per kWh since before the turn of the millennium; at the same time, cumulative wind capacity has skyrocketed. The big growth on the distributed side, meanwhile, has been in solar. In the first quarter of 2016, solar accounted for 64% of all new electric generating capacity brought online in the United States.

The reason that wind, solar, and natural gas combined cycle (NGCC) plants have received the largest investments is that they are the cheapest. When looking at the unsubsidized levelized cost of energy (LCOE), NGCC plants are the only conventional resources really in the mix. Coal generation has been declining in the United States (and in the OECD countries generally). In addition, about half of the nuclear reactors in the United States now are losing money – around $3 billion per year; these are in a mix of competitive and regulated markets, though there is much less visibility into regulated markets

The Transportation Sector

Cleaning up the transportation sector is challenging, as the sector is more than 90% reliant on fossil fuels. The transformation of the sector is only partly a technological challenge; it is also about leadership, policy, capital deployment, and several other factors and trends.

Electrification of Light-Duty Vehicles

There is no coherent set of national policies to address the transportation transformation, either from a decarbonization or enhanced customer experience perspective. If a default national policy or preference seems to be developing consistent with decarbonization, it appears to be electrification. The transportation and electricity sectors are starting to integrate; Ford's industry and Edison's industry are merging to eat Rockefeller's.

The conventional wisdom of where transport is heading is clearly changing rapidly. Just a few years ago, electric vehicles (EVs) were seen as kind of out there, but the precipitous drop in lithium-ion battery prices means auto markets could be transformed faster than anticipated. Based just on sticker price, many consumers may not want to buy EVs until the mid-2020s, at which point they are expected to really take off, but the boom could certainly happen faster. The number, quality, and variety of vehicles available will help drive the transition; over 200 different models of EVs are expected to be available by 2020, including vehicles with bigger ranges. Some automakers have pledged to produce only EVs within a few years, while some countries have pledged to stop selling internal combustion engine vehicles within the next decade or two. Utilities, too, have shown phenomenal interest in vehicle electrification and are pushing EV charging infrastructure, recognizing the opportunity presented by a potential new source of load amidst otherwise flat or declining demand. (Often, however, utilities are prevented or limited by their commissions from advancing EV charging solutions.) In addition, many of the emerging business and utilization models, such as autonomous vehicles and vehicle-sharing, are strongly advantageous to EVs; with likely fleet ownership of such vehicles, the cheaper fuel and maintenance of EVs may carry the day. Some experts project that about one-third of all cars on the road and almost half of all light-duty vehicles sold in 2040 will be electric vehicles. While projections on EV deployment vary, they all seem to get revised upward every year. The transition to electrification is starting to be seen as something that will happen in some form, with the main question being how quickly.

> Lithium-ion battery prices are projected to keep declining to under $100/kWh before 2030.

The path to widespread vehicle electrification depends on many things. The batteries themselves are a critical factor. Lithium-ion battery prices are projected to keep declining to under $100/kWh before 2030, but the cost of batteries actually may not need to come down much more for batteries to succeed; as deployment increases, it should be easier to capture the revenue from the grid value that plugged-in EVs can provide, which can repay a good portion of the vehicles' sticker price. Reducing drag and light-weighting vehicles (e.g., by using carbon fiber) can also allow for fewer batteries to be needed. In addition, new batteries could change everything. There are energy storage options that will be better than lithium-ion, perhaps both in chemistries (e.g., lithium-sulfur) and design (e.g., flow batteries). Solid polymer electrolyte batteries, for instance, could be compatible with a range of chemistries, much cheaper than lithium-ion, energy dense, and cheap to manufacture, in addition to having a good cycle life and involving nothing toxic, rare, or flammable. A critical challenge, however, is figuring out second-life applications for vehicle batteries. Batteries do not have to degrade that much to no longer be useful for vehicles, but they can still provide stationary source grid services. While it has thus far proven challenging to develop a viable business model and to address liability concerns, it would be unfortunate to lose that sizable remaining capacity.

The toolbox of solutions for electrifying the light-duty vehicle fleet is not just limited to batteries, and it would be advisable to have any changes in policy that are geared towards the electrification of transportation be technology-neutral, to keep all tools in the toolbox. For example, hydrogen fuel cell vehicles could potentially offer greater scalability than battery EVs, as they could be used for both small and large vehicles and for both short and long ranges. The technologies mostly exist already, but fuel cell vehicles are limited by a lack of infrastructure buildout, high costs for making hydrogen for transportation, and a need to advance low-carbon approaches to hydrogen production.

Policy, of course, is another key factor influencing the path to vehicle electrification. The auto industry started getting heavily regulated around the late 1970s, when it was forced to improve the fuel economy of cars. Now the industry is being pushed to take exhaust emissions completely off the table, both by step-wise federal regulations and by stringent state standards such as California's Zero-Emission Vehicle mandate, a convoluted policy that has been changed numerous times and arguably gets ahead of what consumers want. Given the scale and long-term nature of investments needed in technological changes, a key feature of regulatory policy ought to be its durability, stability, and long-term nature – as well as flexibility to allow for growth in market segments that do not exist today. Although manufacturers need some level of certainty in the marketplace in order to know what to produce, the Trump Administration is seeking to reopen a lot of the current regulatory approaches related to fuel efficiency and transportation emissions.

The extent to which electric vehicles proliferate on the roads also depends on how quickly existing internal combustion engine vehicles get off those roads. Turnover of the vehicle fleet takes time. The average lifetime of a vehicle used to be about 12 years, but as oil prices go down and the delta shrinks between new and existing vehicle prices, the scrappage rate of vehicles has declined. People are driving their cars for longer now – closer to 15-17 years. It is possible, though, that scrappage rates might start to increase again due to increased utilization, such as from ridesharing vehicles being used more often, which would increase the rate of fleet turnover and help increase the penetration of cleaner, more efficient vehicles.

Making Fleets Cleaner

Transportation and logistics industries are currently enormously dependent on fossil fuels – mostly diesel. That lack of diversification, coupled with the associated environmental and climate aspects, makes it an imperative to find other solutions.

Owners of large fleets have been focused on improving vehicle efficiency for years. Improving the efficiency of fleets is seen as a competitive advantage, so corporations have an incentive not to share what they have learned – but they ought to, as deep, broad collaboration will be key to making widespread gains. There is also a need for big corporations to bring smaller fleets along; most fleets have fewer than 10 trucks and do not have the resources that the larger fleets do to move toward efficiency and cleaner fuels. Smaller fleets and individual trucking companies are quite sensitive to fuel price changes; if larger fleets can help bring technology prices down, the substantial cost savings will bring smaller fleets on board as well.

Owners of large fleets have been focused on improving vehicle efficiency for years.

Beyond efficiency, options for improving heavy-duty fleet vehicles depend on the vehicles' duty cycles – how far they have to go, how often they stop, how long it takes to refuel, how much cargo they are carrying, and so forth. Long-haul trucking is different than city delivery, and the technologies that can improve each duty cycle may differ. For example, electrification or hybridization for a heavy-duty truck might make sense for something like a refuse vehicle, which has a lot of stop-and-go, but might make less sense for highway vehicles. Another key issue with batteries in transport logistics is weight; companies do not want to have to carry so many batteries and so much weight on a truck that they are leaving freight on the dock. While some nevertheless feel that electrification can work in all fleet applications, many fuels could potentially play a role.

Some companies are looking at and testing next-generation biofuels, renewable diesels, and other fuels. For the most part, though, liquid fuels with better carbon footprints that can be done at scale do not appear to be on the near horizon. Some big companies have assessed the options and the state of the technology and have decided to keep focusing on research, as the existing options were insufficiently appealing when considering carbon footprint, environmental footprint, scale, and cost. At the current stage of technological development, for instance, fuels such as algae biofuels may be best suited for chemical production; the technology and risk are not conducive to the fuels market yet.

In addition, moving into a poly-fueled future gives rise to a need for more complex facilities that have the infrastructure needed to provide different fuels to different fleet vehicles. Complexity is costly, as are the potential implications of complexity on operations, maintenance, retraining of mechanics, and other factors. People also live by these maintenance and fueling facilities, raising potential environmental justice concerns that require engagement and solutions. Engagement with communities is an opportunity for partnership.

Scale is a perennial challenge. Ideas have to actually be applied, at scale, in order to be game changers. Leading corporations seeking to reduce or eliminate the impacts of their operations, however, cannot buy what they cannot buy; there have been many challenges finding the right clean/advanced technologies in the transportation and logistics space. Unlike the light-duty vehicle sector, there are only a few manufacturers addressing the different types of duty cycles for heavy-duty vehicles, the manufacturers that have been in this space keep changing, and not all of them can produce at the scale large corporations require – not in the tens or hundreds of vehicles but in the thousands and tens of thousands. For instance, there are alternative fuel providers with interesting technologies that approach big companies, but they can only provide small batches of fuels, which big companies would blow through rapidly. Big companies cannot prove out technologies at such small scale.

Getting to a sustainable base of suppliers of new technologies and fuels may require an initial focus on smaller transport logistics vehicles, where smaller cargo capacities make it possible to build on the success in the light-duty vehicle sector. As progress is made on that beachhead, and as the technologies improve and get less expensive, the focus can continue to move up the scale. Policy experts often try to start from the heavy side and work down, but that is a failed approach; it makes more sense to start with the progress already made in light-duty vehicles and work up.

Transportation and logistics fleets, of course, do not just consist of trucks. Electrification and automation may increase in aircraft, but probably less in propulsion than in all the other ancillary aspects. While some are working on planes propelled purely by battery power, there are concerns about range anxiety, payload weight and capacity, and other issues. As for trains, they move a huge amount of freight for a fraction of the energy of trucks, and there are only a few tens of thousands of train locomotives, which is a small number to switch out to cleaner and more efficient models. On the other hand, while the efficiency and ability to decarbonize are certainly there, questions still remain about rail's viability for some businesses; trains do not have anywhere near the flexibility that trucks do, and the distance the load has to travel matters a lot as well.

Distributed Energy Resources & Retail Market Disruptions

Distributed energy resources (DERs) are upending retail markets and the structure of the distribution system. DERs could be a critical part of achieving secure, clean energy.

Distributed, Flexible Energy Resources

The electricity world used to be relatively small, mostly consisting of utilities and public utilities commissions. Independent power producers then joined, but it was still small. With DERs, that world has become much bigger and more chaotic, with more – and more diverse – participants than before. Value in the electricity system is shifting from central generation out to transmission and distribution. This electricity inversion – the move from centralized to decentralized systems – may well be a generational investment opportunity.

Value in the electricity system is shifting from central generation out to transmission and distribution.

DERs are much broader and more transformational than just the poster child of rooftop solar. DERs can encompass a wide range of other technologies, including distributed wind, combined heat and power, on-site energy storage, microgrids, energy efficiency, demand response, electric vehicles, and much more. In addition, DERs can include enabling technologies, such as advanced/smart metering (which provide insight into the state of the grid, so the DERs can be told what is needed from them and when), home and building energy management systems, distribution management systems, and power electronics (e.g., smart inverters). Energy systems integration represents a big opportunity to enable clean energy technologies; while generation and demand technologies are clearly important, so are technologies that enable them to be used and accessed.

DERs excel at enabling flexible loads with following capabilities, which may well be a prerequisite for having the growth in low-carbon generation really boom. Many DER technologies are gaining momentum. Energy efficiency, demand response, and other demand-side resources, for example, have strong track records of being extremely inexpensive and effective options for reducing load, and there are tremendous win-win opportunities to use technology to perform energy efficiency retrofits in big institutions with a good return on investment. Solar and storage costs are also coming down, which could be a game changer, as solar plus storage is basically equivalent to baseload power; the opportunity for combining rooftop solar and storage is beginning to enter the

DERs excel at enabling flexible loads with following capabilities, which may well be a prerequisite for having the growth in low-carbon generation really boom.

market in some states. Economies of scale could help drive battery storage costs down even further, as a tidal wave of battery manufacturing accelerates. In addition, community solar is beginning to gain momentum, and community solar too can be paired with storage.

> Economies of scale could help drive battery storage costs down even further, as a tidal wave of battery manufacturing accelerates.

There are other potential flexibility resources that could be used on the grid as well. For instance, thermal storage – whether molten salt, ice, chilled water, or something else – can provide enormous flexibility. Peak air conditioning load drives a lot of the investment and cost in the grid, but many buildings have the capability to combine their HVAC systems with banks of ice tanks; this is a mature but relatively untapped technology. Buildings with full ice storage – making ice off peak, melting it on peak – can eliminate an enormous amount of air conditioning load during peak energy consumption, basically taking out everything but ventilation. Wastewater treatment plants, of which there are about 15,000 nationally, represent another simple and underutilized opportunity, as these plants can use their flow diversion ponds to move the water treatment process out of peak. Besides wastewater treatment plants, other facilities that have load late into the evening – including hospitals, hotels, prisons, and others – represent opportunities to create more flexible resources. Datacenters, with their backup generators and storage capabilities, could potentially be grid resources as well. At the residential level, another efficient flexibility solution would be having load chase supply, which becomes an increasingly powerful option with artificial intelligence and machine learning. People want their dishes done, but often do not care when precisely their dishwashers run; that load can be shifted to times of abundant supply.

Utilities, the Grid, and DERs

There are many benefits to utilities and the grid from DERs, such as adding flexible energy resources, improving local resilience, enabling consumer choice, helping the environment, and creating the potential for capex and opex deferral. From an operational perspective, however, the new DER technologies present challenges for utilities, as their systems and business models fundamentally are not designed for DERs.

> New DER technologies present challenges for utilities, as their systems and business models fundamentally are not designed for DERs

Utilities are not incentivized to invest in grid integration of DERs, as DERs represent real revenue erosion possibilities for utilities, which currently make money on volumetric sales. The utility business model has been off-track for a while. Edison sold light, not electricity, which meant improved lighting efficiency reduced his costs and raised his profits. The industry, however, switched to selling kilowatt-hours (except in street lighting), which means improvements in customers' efficiency reduce revenue.

DERs also inject great uncertainty, as utilities are no longer in control of everything connected to their systems. What happens behind the meter is invisible to utilities, which makes it hard for them to forecast and plan for potentially large changes in load profiles; utilities have to start operating and planning in a stochastic rather than a deterministic world. There is a striking contrast between the planning needed for capital investment by utilities and the unleashed chaos happening behind the meter, with hundreds of millions of customers engaging in individual transactions. If utilities can find ways to drive and embrace the chaos – which, admittedly, will be a tough adjustment – then the result will be huge uptake and benefits; if utilities instead try to keep things to a level of manageable simplicity, the results will be mediocre at best.

The uncertainty created by the proliferation of DERs extends to security as well. In 2015, the energy sector was the second-largest target for cyberattacks, with power companies and utilities around the world experiencing a six-fold increase in detected cyber incidents over the previous year. It likely is not a coincidence that cyberattacks spiked starting in 2010, around the same time as the huge increase in investment in smart grid technologies. On the distributed side, even as more DERs are connected to the grid, security continues to be an afterthought. There is a cost to cybersecurity, and at some point, someone has to pay to build security into the system. Security is like insurance; it is a question of how much risk one is willing to take.

> Power companies and utilities around the world experiencing a six-fold increase in detected cyber incidents.

In addition, DERs raise some fundamental questions about the purpose of utilities. The social compact seems to be expanding from just providing universal, affordable, and reliable electricity service; it now also includes accounting for additional factors such as decarbonization, customer choice, and social equity. The ones utilizing the DERs are generally the tech-savvy first adopters, who are the most economically well off, raising issues of equity for low- and middle-income communities. Utilities are then torn between scaling DERs because of the positive effects on carbon emissions and customer choice and the real cost-shifting problems that may be unfair to disadvantaged communities. There are tensions within the broader scope of utilities' new social compact obligations.

Furthermore, there are physical impacts to DER deployment, as the system was built for one-way, centralized, steady, dispatchable 60 Hz power flow. The grid is evolving, however, into a more modern grid, with bi-directional power flow, a lot of variable generation, and changing load profiles. This can affect existing grid equipment. For instance, as electric vehicles reach higher levels of penetration, more vehicle charging could start occurring in the evening, which is when electricity system infrastructure often currently cools down; the lack of a cooling down period could change the wear and tear on that infrastructure.

A grid architecture that combines both distributed and bulk power resources is enormously complicated, reflecting a fundamentally different paradigm. DERs offer the opportunity for a more distributed and dynamic grid architecture, but that is not yet a reality. Most utilities have very low levels of DER adoption, using technologies for basic grid modernization efforts such as outage management. A few utilities are at a somewhat more advanced stage, with moderate to high levels of DER integration and the beginnings of efforts to develop the distribution system as a platform for DERs to interact. No utilities, however, are at a truly advanced stage, with very high levels of DER adoption and multi-party interactions in distributed markets. It has not been clearly thought through how it will work when communities and towns are interacting among themselves; there may not even be a need for a bulk power system. As DERs continue to proliferate over the next decade, there will be a need for some kind of coordinator at the distribution stage, similar to independent system operators (ISOs) at the wholesale level.

Utilities that want to advance DER integration can face sizable hurdles. For instance, widespread deployment of DERs will lead to massive data loads, which have to be handled, understood, and fed into policies and standards. Utilities that want to act as platform providers for DERs are generally not well-equipped to do huge amounts of data crunching. Combining the skill sets of utilities and Silicon Valley could prove out the model, but that is not an easy combination. Utility investors are looking for low-risk, long-duration investments. Utilities are not structured or incentivized to be Silicon Valley; they are there to keep the wires working flawlessly. Utilities can put constraints on themselves in terms of unwillingness to take risks, but failure is a key part of innovation. Some utilities are exploring partnership models in which they can provide the data and concepts and work with technology providers to provide solutions, but for the most part, such partnerships with utilities are far from ubiquitous.

While technology and software can be powerful forces in a free and open market, the state-by-state regulatory model presents an obstacle. Regulators generally move at a glacial pace compared to technology and customer needs, making it even harder for utilities to move swiftly. Given the constraining regulatory model under which they operate, utilities are instead finding new and interesting ways to rate-base projects (e.g., repowering old wind turbines, grid modernization). Even unregulated power providers face constraints. Many co-ops are somewhat captive within the transmission and infrastructure systems of larger investor-owned utilities, and some co-ops and munis are also constrained by caps on self-generation placed on them by their generation and transmission providers, which can stop a lot of distributed renewable generation. In addition, all power providers have existing systems and existing customer needs, which constrain their options moving forward.

Utilities have an opportunity to create new dialogues with core constituencies around DERs, resilience, sustainability, and climate. Having everyone together at the table as stakeholders can lead to collaborative problem-solving and can break down balkanization. If the goal is to accelerate clean energy at the customer level, then technology and solution providers need to partner with customer groups and utilities to identify big, broadly applicable wins that create new business opportunities without destroying utility value. These collaborators can then work together to bring new solutions to regulators or governing boards to accelerate the transformation.

Customers, Competition, and Choice

Big customers, who have the economic heft and mission requirements, will be among the main drivers of DER deployment. With the range of DER technologies, the first entities to leave the grid – or at least create a very different economic relationship with the grid – will be the customers whose need for electricity, resilience, and security is the highest from a business point of view. These include the military, datacenters, hospitals, manufacturing plants, and the like; those who can afford to control their own destinies and for whom electricity is mission-critical will do it first.

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The clean energy industry has been behind in the conversation on resilience and security. Rather than being defensive, it needs to go on offense, making the case that DERs and renewables can solve real energy security problems for customers. The Department of Defense, for instance, has a holistic focus on energy that encompasses resilience, cost, and cleanliness, in that order. The military trusts the grid for the most part, as it is rather resilient, but the military has to be prepared to separate its facilities, island its bases, and have its own on-base capabilities to complete missions. Renewables are beneficial because they have an uninterruptible supply chain, and if the electrons needed for a mission cannot be interrupted, the mission is more secure. The same is true with other forms of distributed generation. The military's ideal is something like a third party that operates distributed generation on military bases as part of a smart, agile, bi-directional, interconnected, cybersecure microgrid, underpinned by mission threat analysis, that lets the military move precise amounts of power where and when needed within an installation. The military is also exploring the concept of energy as a service, seeking providers who can provide key energy services – light, heat, resilience, etc. – for a flat price.

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When customer choice in procuring clean energy is an option, demand has been quite strong. For instance, most Fortune 100 companies have significant renewable energy goals, and more and more companies are looking to move beyond buying Renewable Energy Credits to directly purchasing renewables instead. Although the volume of publicly announced contracted renewables capacity declined from 2015 to 2016, more than 6 GW of corporate power purchase agreements (PPAs) have been done over the past few years. The Corporate Renewable Energy Buyers Group alone has committed to purchase 60GW by 2025. Corporate buyers for electricity like renewables because they are predictable and have zero fuel cost. Increasingly, organizations representing hospitals, universities, cities, and other large buyers of energy are interested in purchasing renewable energy as well. It is a buyer's market; the biggest companies have taken the initial steps on renewable PPAs, but it is not just a market for the biggest players anymore.

Most of the corporate deals have occurred in deregulated markets. Competition, where it is happening, is driving savings and looking like a viable path to large amounts of clean energy. In contrast, customers who want to buy clean energy in regulated markets often encounter greater challenges. For instance, big tech company customers that want to get to zero carbon or 100% renewables as fast as possible are negotiating complicated, buyer-specific, one-off deals with utilities. Some have had to pay substantial exit fees in order to leave their utilities, but they are willing to pay to stop being customers partly because of the widening gap between retail and wholesale prices. From 2004 to 2016, wholesale prices declined 41%, while retail prices rose 40%; while the level of disparity varies locally, that is a huge delta for the U.S. electricity system and U.S. retail customers generally. Even with the exit fees, big customers can end up saving money by leaving retail rates. (The headroom utilities have in the gap between wholesale and retail prices is in some cases being used to cover the high costs of modernizing the transmission and distribution grid infrastructure to move power around in a more dynamic system.) In addition, big customers are showing little tolerance for having to wait a long time for utilities to get approval from regulatory commissions, and customers should think more about how to work at public utilities commissions to influence some of the structural barriers to greater customer choice.

Not everyone, though, is a big consumer that can forge an individual energy path. Community choice aggregation (CCA) could be thought of as the average person's opportunity for choice. Aggregation programs are growing – another example of the strong demand for choice when it is an option – with over one million customers in CCA programs across the country, many of them in California. In some states, CCAs are opt-in, while in others they are opt-out (which makes them a bit less of a true choice). CCAs have benefits for consumers, who theoretically can access more and cheaper clean energy, as well as for local governments, for whom CCAs can be revenue-generating opportunities. CCAs may also enhance the value of utilities, as others increasingly use their infrastructure, though there can be challenges with regulatory rate designs leading to non-CCA customers paying a disproportionate share of system charges.

Competition and retail choice matter because each consumer has different interests. Understanding of customer segmentation is important, but as customer engagement grows over the next decade, utilities will need more sophistication with regard to customer choice. Customer needs and capabilities vary widely within a given utility territory, much less across utilities or states. Some customers, for instance, are realizing that they can buy fewer and cleaner electrons and produce some of their own; utilities may be better off selling them what they want before someone else does. It is possible that all the services that some customers want are behind the meter and could be provided as part of a basic financial transaction, negating the need to even have a meter. Utilities that want to be more customer-centric may also want to appeal to customers worried about grid failure by no longer forbidding – and perhaps encouraging if not requiring – distributed source hookups to be resilient to work with or without the grid. However, there are customers on the other end of the spectrum too. Many customers will choose not to do anything different, and whatever system is set up to facilitate customer choice has to support that choice as well. Many customers also still have pretty basic needs, and many utilities need to get basic, front-end, customer-facing retail functionality in place before they can be conduits for products and services that facilitate customer choice and interaction. In addition, customers do not always know what they want, as exemplified by Henry Ford's comment that customers would have asked for a faster horse, not even knowing a car was an option. As customer engagement increases, the customer could well emerge as the most intermittent, variable resource in the whole system.

Policies

In a technologically disruptive world, governments are not usually the speediest responders to the changes that are occurring. Even when the status quo plainly is not working, change is very hard to deliver in government. Government may need to be better at embracing risk; failure has to be allowed, as it is always a possibility when government is actually trying to fix things.

States are an exciting place for policy innovation, and state policies are a key ingredient in broadening DER adoption. State policies on rates, permitting, taxes, and interconnection are critical. Policies implementing retail real-time pricing, for instance, can help drive more energy consumption during periods when the load is negative (e.g., during the mid-day solar peak) and can allow smart devices to aggregate loads and respond automatically to price signals in ways individual customers hardly notice. Real-time pricing does not need to cover every consumer in the market, but the value proposition is not a complicated one to convey to customers. If real-time pricing policies can be implemented well, then the race will be on to get low-cost devices into homes or to pursue other strategies to shift loads to times of peak renewable generation.

States are an exciting place for policy innovation, and state policies are a key ingredient in broadening DER adoption.

States on the West Coast and in the Northeast are leading the pack in adopting policies seeking to unleash the potential of DERs. Some states have used reverse auctions to harness the power of competition and get cheaper renewable energy results. New York has been pursuing its Reforming the Energy Vision (REV) initiative, which is creating a new tariff structure that moves from net metering to new structures that better value DERs' energy, capacity, and environmental attributes, as well as a market transition credit (for a period of time). Connecticut set up a green bank, which has proven to be a successful model for pushing renewable energy and energy efficiency projects to greater scale by using limited public resources to leverage private capital to fill holes in the market. California has instituted a range of policies to advance DERs. For instance, California in 2010 set a storage procurement target, knowing there would be a need for greater storage in the future; when the Aliso Canyon incident occurred, the reason the state could procure so much storage so quickly was because vendors had projects in the works.

There are tensions in California policy, though. California customers clearly want more clean energy and energy efficiency and are willing to pay more for them, but California utilities are handcuffed in not being able to offer customers what CCAs can. California policies also may not be doing the right thing for energy efficiency. The state has dozens and dozens of specific energy efficiency programs, some of which go back 40 years, and not all are good uses of customer money, but the cottage industries that support the existing programs influence state agency staff to perpetuate those programs. In addition, Californian subsidies for rooftop solar and EVs, which tend to go to the wealthier populations, are much bigger than the subsidies available in the low-income program; this is a wealth transfer from poor to rich.

There are opportunities, though, to use state policies to expand access to DERs and clean energy. Low-income customers that do not own their roofs and do not have high FICO scores could be served well by policies enabling and promoting community solar, yet nearly two dozen states still lack such legislation. Community solar combined with storage can provide significant resilience. It can also push power – electrical and political – out to low-income seniors, multifamily dwellers, and renters and help break down political barriers to clean energy goals. While potentially inefficient from a macroeconomic perspective, DERs can create lots of political disruption and create new political constituencies; people see the jobs involved much more clearly. In addition, there are opportunities in a lot of red states around resilience policy. For example, if insurance laws are set up right, it could lead to huge revenue streams for microgrids and other DERs that bolster resilience and can reduce insurance premiums.

In addition to direct policy support, there are some non-obvious state policy measures that could be of enormous help, such as requiring upgrades of utility back-office systems to support DERs. For instance, state policies on consolidated billing greatly affect the feasibility of CCAs and the broader ability of retail choice providers to thrive; where utilities' billing software is not eligible for cost recovery or where state policies do not otherwise facilitate consolidated billing, utilities have been stalling in providing help to third-party companies. Retail choice providers are also struggling in some states to structure products for customers due to the absence of upfront data-sharing requirements, as it is hard to structure products without access to utilities' smart meter data.

Not all the policy action is in the states. Federal policy can be both a key driver and inhibitor of DER deployment as well. Federal investment tax credit benefits are roughly 40% of the cap stack of an average solar project, which is significant, but there are only 25-30 large institutions with a tax equity appetite; there is a need to radically increase the number of institutions that will invest in tax equity. Given the political power of incumbency, federal policy can also try to stop some of these transformations, as it has in the past, though the technologies now are more mature, more diverse, and closer to market. Federal trade policy could pose another threat to accelerated DER deployment.

In general, government policies should be focused on outcomes – resilience, safety, security, affordability, carbon, air pollution, water pollution, and more – and take advantage of innovation to achieve them. There are concerns, though, that pushing DERs to the top of the policy agenda creates a distraction in the pursuit of larger goals. Many DER issues will get worked out between consumers and vendors in individual capitalist transactions. Focusing on DERs in front of the Federal Energy Regulatory Commission (FERC) and other policy makers could distract from a focus on retiring coal plants, paying for stranded assets, getting multiple gigawatts of utility-scale renewables on the grid, achieving big reductions in greenhouse gas emissions, and the like. On the other hand, utilities have to be in business in order to achieve reductions, and policy support is needed in order for their customers to get what they want.

Wholesale Market Disruptions

The changing nature of the U.S. generation mix and state efforts to protect resources that are struggling economically are creating serious disruptions in wholesale markets.

Generation Resources & Grid Reliability

The nation's generation resources are in flux. Coal, nuclear, and hydro plants tend to be older and highly depreciated, and some of these older plants are at the stage of making decisions about retiring or retrofitting. Wind and solar plants, in contrast, are much newer and less depreciated (though there is some ambiguity on the actual lifetimes of wind turbines), and there has been movement to repower existing towers and pads with newer technologies that are cheaper to maintain. Almost everything new being built in the United States is wind, solar, and natural gas.

The changes in generation resources have led to debates about the effect of renewables on baseload resources, on the economics of incumbents, and on the reliability of the grid. On the baseload question, it may be that the concept of baseload is obsolete and needlessly complicating energy conversations. Baseload power – running and needed all the time – made sense in the past, but the technological revolution that has brought a boom in solar, wind, and other disruptive technologies has made controlling the grid more adaptable. There are now other options for a different system. While there may or may not be a need to retire what exists, policies should not be oriented around protecting baseload. The flood of zero-carbon, zero-marginal-cost renewables does seem to be hurting incumbents, but it seems clear that the influx of renewable energy is not causing problems for the reliability and management of the grid. Grid management costs in Texas actually went down despite the rise in wind, due to market design improvements, better wind forecasting, geographic dispersion of wind, and the availability of fast-ramping natural gas generators.

Further analysis is needed to get a true understanding and comparison of the range of hidden costs involved in various energy resources. Intermittent renewables, for instance, impose wear and tear on gas peaker plants that have to ramp quickly. On the other hand, grid integration costs for centralized thermal systems might well be higher than for variable renewables, though such costs often go unanalyzed because they are seen as essential system costs.

Challenges in Wholesale Markets

In the parts of the country that have wholesale markets, wholesale prices continue to plummet because of low natural gas prices, as well as zero-marginal-cost renewables and stagnant demand. Gas sets the market ceiling, and renewables set the market floor. Nuclear, which was not built to operate in that band, is getting squeezed from both sides. Likewise, coal cannot come back in the United States as long as natural gas is cheap. Even relatively new natural gas combined cycle plants are going bankrupt.

In wholesale markets, wholesale prices continue to plummet because of low natural gas prices, as well as zero-marginal-cost renewables and stagnant demand.

The challenges occurring in the wholesale market represent, in some ways, a teachable moment about the potential power of renewable energy in the marketplace. The current market, as designed by FERC and others a couple of decades ago, is not well-suited for a market flush with renewables with zero marginal cost. Because electricity is traded on the margin, zero-marginal-cost renewables coming into the system cause wholesale prices to collapse. When locational marginal prices are basically zero, then the power price is no longer the driver of the market; one could ask whether it is even still a market, as opposed to a totally different system in which the power price is basically relative to the sun and wind. The result is no real market support for some companies' generation, which in turn can lead to political backlash and out-of-market solutions that will limit renewables penetration.

It is important to determine whether there is actually a crisis in competitive markets or simply a crisis of faith in competition. In many ways, it seems more like the latter. For instance, independent power producers in competitive markets are sitting on some increasingly worthless or uneconomic assets. It is understandable that some are pushing for re-regulation in that environment, so they can get guaranteed returns on their assets, but the independent power producer model is now obsolete. They are being wiped out in a process of creative destruction. That is the nature of competition.

Similarly, the out-of-market subsidies to large nuclear generating units or out-of-market PPAs to coal units demonstrate a crisis of faith in competition. The industry is at a crossroads regarding commitment to market operations at the wholesale level; every one-off action erodes the robustness of the markets. If all the deals are out-of-market, then there is no market at all. There has been great attention to the out-of-market supports that New York and Illinois implemented for nuclear, but many states also have renewable portfolio standards and other supports for renewables; the treatment of and reaction to these types of out-of-market supports should be more consistent regardless of fuel type. The issue is one of competitive markets versus individual states wanting to do things that distort market expectations (for better or worse).

There will be a crisis in competitive markets only if people stop accepting the verdict of the markets and intervene to undermine their basic principles. That said, competitive markets are not an end in themselves. The United States does not really have “free” competitive markets; they are all designed and constrained to account for various interests, goals, and actors. Market design is rarely meant to be static; it will evolve over time in response to various pressures, but there can be a time lag before design fixes are implemented to create something better. The wholesale markets have generally operated as intended, providing the lowest-cost resources for consumers, but they are a work in progress, by their nature having to always catch up, change, and evolve as technology does.

There is a need to reform the markets. The fundamental issue, at its core, appears to be that the wholesale markets are not optimizing across things that people care about. For instance, the state responses to the challenge, such as the out-of-market actions by Illinois and New York, are designed to preserve zero-carbon generation and jobs; they highlight the fact that the market does not currently value those attributes. An attribute-based price signal can tell technology companies the size of the hole and let them rush in to fill it (though some attributes may be better dealt with at the distribution level).

Some mechanism to value zero-emissions generation has to be found that is as undistorting and easy to standardize as possible. Carbon pricing remains for many the first, best solution. Even if a carbon price starts low, it could be designed to rise consistently over time, and the long-term price would change capital investment decision criteria. There are already low carbon prices in California and in the Northeast and Mid-Atlantic states, though, and nuclear is encountering the same issues there, so carbon prices have to get rather high in order to meaningfully influence energy choices. That reality, combined with the politics around carbon pricing, would suggest that carbon prices may not be a near-term solution for wholesale markets.

There are numerous other potential options. Wholesale market design reform, with a grand shift from generation dispatch to a capacity availability model, could accomplish several different ends. For instance, it could extend coal plants an economic lifeline for being online and available, even if they are never (or rarely) actually run and dispatched. Another option is to require regional power pools to take account of gas price volatility, which has a market value that roughly doubles the gas price; this follows basic financial economics, adjusting the risk to compare a volatile cost stream to a fixed one, and would help resources compete against natural gas. One could also extend the locational marginal price concept to the distribution node, which would force a re-evaluation of the relationship with wholesale markets. At a higher level, another approach could be a national portfolio standard, allocating pieces of the market to different technologies.

While some view healthy wholesale markets as being key to innovation, others question whether distinct wholesale and retail markets will be sustained over the next decade; just as the wall between supply and demand has grown blurrier, so too might the wall between wholesale and retail. In a world of distributed solar, microgrids, and other DERs, there is a question as to whether wholesale markets and institutions such as ISOs are still needed as much. There may be a moment of reckoning when the whole system has to be restructured, and the tipping points are closer than some think.

The Role of FERC

State policies are affecting interstate wholesale markets in a way that FERC – as the entity that oversees the reliability of the grid and enforces wholesale market rules – has to speak to, one way or another. While state regulators are trying to be responsive to a range of actors and interests, FERC answers only to Congress and makes decisions based on the law, precedent, and the facts of each particular case.

The new FERC commissioners represent an opportunity for engagement and education on the issues surrounding wholesale markets. In the past, FERC should perhaps have done more on the issue of bringing aggregated demand response and distributed energy production – which are basically a form of capacity – under FERC jurisdiction to let them compete. It seems unlikely, though, that FERC will be working on that much in the near future. These new commissioners will not be focused on valuing clean energy resources, but rather on improving competitive markets. The price formation docket at FERC will be particularly important

Deep Decarbonization

Despite all the progress made in clean energy, it is essential to remember that humanity has thus far been failing with regard to carbon dioxide emissions. Deep decarbonization must be a constant organizing principle that guides the evolution of energy systems. Deep decarbonization represents an opportunity both to address an existential threat and to highlight the value creation opportunities of clean energy.

Pathways

It is not possible to forget about the problem of climate change and focus only on solutions. The problem has to be understood. Humanity is running a dangerous science experiment at the moment, with rising greenhouse gas concentrations in the atmosphere. While the science is complicated, the math to 450 parts per million in the atmosphere is not; given that the planet is already at 407 ppm in July 2017, it is likely that 450 ppm will be crossed by 2030. Limiting atmospheric concentrations to 450 ppm is basically unattainable unless massive carbon sinks or geoengineering are considered. Keeping to under 500 ppm might be a stretch goal, while 550 ppm may be a more realistic ceiling. Failing to take action could mean 700 or 800 ppm by the end of the century. Climate impacts are being experienced today, and a lot of warming is already locked in. Serious efforts are needed to reduce the dramatic effects of humanity's science experiment.

Climate impacts are being experienced today, and a lot of warming is already locked in.

Deep decarbonization requires 80% reductions in emissions by 2050 in every developed nation and 50% in every major developing nation. 2050 is not that far away. The goal should be to achieve as many reductions as possible in the near term (10-15 years), which helps de-risk the medium term and allows for new options to be deployed in the long term. At least $10 trillion will be spent on the electricity system globally in the next 10-15 years; that is a lot of money that can be pointed towards low-carbon energy technologies.

The power sector will be responsible for a sizable portion of the deep decarbonization effort, as it is an easier sector to deeply decarbonize than transport or industry. Shallow decarbonization is pretty easy in the power sector, and the work done in preparation for the Clean Power Plan has shown decarbonization pathways forward. Getting to deep decarbonization, though, will require much more than what is currently occurring; the electricity sector has to get to zero emissions relatively soon, and certainly by 2050.

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Not every near-term pathway to shallow decarbonization will get to deep decarbonization, and choices made (or not made) now will be critical to determining the pathway taken. Care must be taken to avoid siren song pathways that dead end or that delay achievement of deep decarbonization. For instance, some are concerned about the huge amount of gas infrastructure being developed in the United States; while this has facilitated shallow decarbonization by displacing coal (depending on what the methane leakage rate is), natural gas is not a zero-carbon fuel. Similarly, because there is not time to go down wrong paths, some are concerned about those who want to bet everything on one uncertain path (e.g., 100% renewables) as opposed to spreading bets out across a range of technologies.

Decarbonization is increasingly accepted in the industry and by regulators as part of the future. The idea is being socialized and accepted in places where people were not comfortable even talking about it before. Decarbonization is the path forward for profitability and economic sustainability in the power sector – and, some argue, for the economy as a whole.

Technologies

Achieving deep decarbonization is not about any one preferred technology. Rather, all technologies have to compete with each other to push out emissions. A rational approach to investment in deep decarbonization would be to figure out the wedges of reductions needed and the key drivers of action, prioritize them, and then apply focused effort and resources in ranked order. Humanity seems to be way off in its allocation of resources and time collectively spent attacking the various wedges.

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There are several buckets of technologies that will have to be involved in the deep decarbonization mix across all sectors. The number one solution is improving energy efficiency by orders of magnitude. There are still a lot of efficiency gains to achieve across all sectors and fuel types – not just in the power sector – and there are hundreds or thousands of technologies active in that space. One key approach to pursue to advance industrial energy efficiency is combined heat and power, as industry is very carbon-intensive and uses a lot of heat (e.g., in manufacturing glass, concrete, and steel). Another technology bucket involves technologies that facilitate end-use electrification, including electrification of industry, buildings, and transport.

Yet another bucket involves energy supply technologies. Renewables can play a big role there, including wind, solar, geothermal, and potentially biomass, biogas, and low-carbon fuels. Whether the goal is 100% renewables, 50% renewables, or some other number, a lot more renewables are needed. Nuclear power also plays a role, while fuel switching to natural gas can be an interim option. The environmental community needs to start getting on board with climate solutions beyond just renewables and efficiency. People have to stop being against everything they are not specifically for. Every technology that is cheaper, cleaner, more resilient, and consistent with deep decarbonization pathways should get adopted and implemented.

Energy supply technologies can only optimize their role in decarbonization because of another bucket of technologies: enabling technologies. In some ways, enabling technologies such as grids, pipelines, storage capacity, and other infrastructure may be the hardest part of the deep decarbonization transformation, as utilities have to figure out how to direct their investments in system infrastructure without a clear roadmap. Clean energy innovation needs to include a focus on technologies such as smart lines and non-wires transmission alternatives. Enabling technologies also include things such as energy storage (e.g., batteries, compressed air, pumped hydro), carbon-free energy carriers (e.g., hydrogen), and carbon capture and storage (CCS), which would allow concentrated energy sources to be part of the deep decarbonization solution set.

Given the enormous challenge of reducing emissions quickly enough, it is likely that humanity will have to rely on technologies that can achieve negative carbon emissions as well. These include biomass with CCS, biofuels with CCS, reforestation, afforestation, and direct air capture with CCS. There are also large decarbonization opportunities in agriculture and forestry that double as adaptation measures, such as increasing sequestration of carbon in soils.

It is in humanity's best interests to keep all the solution options on the table, particularly since applicable solutions can vary widely between and even within countries. Taking options off the table can make achievement of climate goals more difficult. For instance, to stay under a 450 ppm scenario, modeling suggests that removing CCS from the toolbox substantially reduces the likelihood of achieving the outcome and significantly increases the costs. While the failure of the Kemper CCS plant is often pointed to as proof of CCS being unworkable and uneconomic, it is important to recognize that the Petra Nova CCS plant is now operating and was completed ahead of schedule and on budget. With no real carbon price, though, CCS mostly remains in niche segments (e.g., enhanced oil recovery). Absent a price on carbon, CCS may not get significant uptake until there is loud, clear leadership in the business community embracing it, as occurred with renewables. On the other hand, the hydrocarbon business may not yet have fully considered the possibility that even without a price on carbon, the hydrogen in hydrocarbons may be worth more without the carbon, providing an incentive for CCS.

A portfolio of options is needed, but it can be hard for some power providers to pursue a big portfolio. For instance, efforts to build a new nuclear plant can suck up all the dollars and attention that could otherwise have gone towards renewables and energy efficiency. In addition, speed has to matter inside the portfolio. Some zero-carbon solutions may not be ubiquitous and scaled until after 2050, but investing in R&D that pays off in 30-40 years should not play a large role in the portfolio (if any), as time is of the essence in decarbonization. Given the importance of speed within the portfolio, it is critical not to forget current resources that have to be preserved. For example, it is important to keep the existing fleet of nuclear power plants operating around the world, as they provide so much of the current zero-carbon power.

Still, although not a single new technology is needed in the developed world to achieve the reductions needed, new advanced technologies can help the world get to zero emissions (and below) faster and cheaper. Deployment of existing technologies and R&D for new technologies are both needed, and both will happen. Low-risk and long-term may be desirable for deploying existing technologies, but low-risk and long-term are the antithesis of innovation, which is inherently risky. There always has to be room in deep decarbonization conversations for new options to come in, whether in terms of plummeting prices for existing technologies or the creation of the next generation of clean technologies. Some used to think that technological innovation, markets, and policies would converge to create a clean energy future. Instead, it seems that markets have become fractured and distorted, while some policies are being forcibly yanked in the other direction. This increases the importance of figuring out how best to promote, incent, and accelerate the pace of socially beneficial innovation. Sometimes, that requires policies that provide stable platforms on which to spur more innovation. Other times, the bigger problem is getting the carcass of incumbents off the track so they do not block innovation from moving forward. Innovation happens faster than most people expect, on exponential curves, and policy has to adapt to or accommodate that.

Technology has lots of upside, but also lots of risk and uncertainty that have to be managed. There are ways to increase the odds of achieving the technologies needed for deep decarbonization, beyond just pursuing a portfolio approach. One is to maintain constancy of purpose – i.e., not starting and stopping research and technological bets. Another is cross-fertilization of innovations from adjacent fields (e.g., biology, genomics, medicine, defense, artificial intelligence). It is also important to recognize that while technology is unpredictable, there are trends it often follows, such as being commercialized first in the highest-value segments and then moving down.

U.S. Policy & Politics

Technology does not live in a vacuum, and markets alone are incapable of dealing with carbon emissions, as they are externalities. There most likely will never be sufficient emission reductions without policies driving them, whether directly or indirectly. Policies matter at all levels, from macro carbon pricing policies to R&D funding to policies that push (or pay for) high-carbon assets to exit the fleet.

There is already a large suite of policies and supports for carbon abatement in the United States, with over 100 federal and state mandates. These include renewable portfolio standards in 37 states, 10 states with greenhouse gas reduction programs, and federal rules on mercury and air toxics, air quality, vehicle fuel efficiency, renewable fuels, lighting efficiency, appliance efficiency, ozone depleting substances, and more. There are billions of dollars in incentives as well. (CCS has thus far received relatively little policy support.) These policies are implied carbon prices – often very large implied carbon prices. Between mandates and subsidies, the nation – on a bipartisan basis – appears very willing to support really high carbon prices, as long as they remain hidden. Almost none of these policies target deep decarbonization, but they involve lots of political players, and they mostly run through 2025 or so. There is a need to get the political class to double down, with some kind of deep decarbonization lever or accelerator sitting on top of all of this. Otherwise, if disruptions from climate impacts get bad

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enough, it is conceivable that efforts to reduce emissions will be overtaken by policy choices that abandon mitigation in favor of adaptation and emergency management.

An increasing, transparent price on carbon would certainly help. While most businesses will comply with mandates and value the certainty that policy can provide, carbon pricing could be a policy framework for the 21st century, treating businesses not as the source of all problems but as providers of solutions, letting them figure out how much to abate and how much to pay. The level of the carbon price will determine if it helps drive towards deep decarbonization or only shallow, but it is an important part of the pathway.

Politics, however, drives policy. Carbon taxes can be structured in ways that are at home with conventional Republican orthodoxy, such as by taxing something undesirable to replace taxes on income. Some people in the Trump Administration looking at tax reform are open to that idea, but it is far from the orthodoxy in Congress right now – or in the Administration among people focused on energy and environmental issues.

The next generation of Americans mostly believes in climate change and expects current leaders to try to foster solutions. Dogma and ideology are preventing action on climate at the federal level. In the Senate, few Republicans will say climate change is real and humans are major contributors to it. This is due in part to the culture of inaction in the Senate. What can help is getting policymakers in closed rooms with scientists they trust and giving them the opportunity to ask hard questions. There is very little policy that does not have a political tinge, and there is likely no path to deep decarbonization that does not involve both sides of the aisle and the broad spectrum of ideologies. Deep decarbonization is a political discussion, and a way has to be found to align politics to get it done. Since climate change and clean energy have become so politically charged in Washington, DC, progress may need to be tied to bipartisan goals such as resilience or to megatrends such as automation, digitization, and urbanization.

Another unifying theme may be American leadership in innovation and research and development. The United States spends hundreds of billions of dollars on its military budget, and it spends far more on health R&D than on energy R&D. Zero-carbon energy has to start becoming more of a national priority for investment. A lot of the research happens at the national labs or is driven by APRA-E programs, but they need funds to provide those capabilities. The Trump budget calls for zeroing out ARPA-E, and the Administration's push for the national labs to go back to basic science widens the valley of death between early-stage research and actual commercialization. Private companies that have made commitments to climate or clean energy goals need to bring their political prowess to bear on Congress to urge support for clean energy R&D and ARPA-E (in addition to carbon pricing); carbon prices and innovative R&D could be key elements of a deep decarbonization pathway. In addition, there is a need to push for action on policies that have nothing to do with climate or energy but that hinder the transboundary nature of science; the Administration's immigration policies, for instance, hinder the ability of scientists to travel to exchange ideas and the ability of universities and companies to do research.

If policymakers will not provide the necessary support for clean energy innovation, perhaps the corporations that have profited from putting carbon into the air could put money into a charitable consortium to fund R&D efforts at ARPA-E and the labs. There are serious doubts, though, about the ability (and willingness) of the private sector to make up for huge cuts in federal R&D funding. A key question is who underwrites the risks of pursuing climate solutions. Finance is a perennial challenge. For instance, if one is starting an advanced nuclear company and wants to raise capital, the prospect list of investors is remarkably short, and many of them have already invested in one. CCS is similar in terms of the scale of investment needed and the long-time frames involved. Big industrial innovation, such as what the United States used to do in the 1950s-1970s, is very different from the Silicon Valley software-driven innovation of today. The huge R&D investments involved in big industrial facilities like CCS may call for socializing the risks in a bigger way. Realistically, Department of Energy support will be needed for such projects, alongside billionaire capital. Specialized experts who can evaluate technologies, such as in ARPA-E, are also tremendously valuable.

Achieving any federal policy goals requires building alliances. Politicians do not think many of their constituents care, and polling shows that while most Americans believe climate change is real, it is always low on people's list of priorities. Advocates of climate action have done a bad job of reaching out to people who, while not their typical political allies, ought to be natural allies in dealing with changing weather and long-term economic transformation. For instance, there is not a farmer in the country who should not believe that climate change is real; they are practical people who know how things have changed and what the effect will be in the future. However, while they are sensitive to the changes in weather and climate, they are repelled by the political conversation around climate change. Agriculture can also have a big role in carbon sequestration; it is worth bringing back the idea of paying farmers and ranchers for soil carbon conservation.

In coal country, the problem is that the people there, through no fault of their own, are on the short end of the stick during this decarbonization transition – and the loss of coal jobs is a subset of a more fundamental job loss in rural America. It is estimated that 45% of all coal-fired power in Western states will be gone in 10 years, and 85-90% in 20 years. In 2016, the three biggest coal producers in Wyoming were all in bankruptcy, largely due to a market that is replacing coal in the West with natural gas and renewables. The Navajo Generating Station voted to close down 25 years early due to economics. These trends will have significant economic disruptions in these areas and will disrupt people's identities and social status as well. If ways are not found to help them and bring them into the clean energy transition, there will be a backlash with political ramifications (as was seen somewhat during the 2016 elections) that could hinder the transition. The Keystone Pipeline, for instance, became a talismanic issue, and many of the people who voted for Trump think the Democratic Party and environmentalists are prioritizing climate change over jobs. There has to be an honest conversation with people in those communities about what is going on in the economy, as well as efforts to put forth

It is estimated that 45% of all coal-fired power in Western states will be gone in 10 years, and 85-90% in 20 years.

economic development policies in those regions. Democrats have not really been having those clear, honest conversations, and Republicans certainly have not been. Talking about people, equity, and justice has to go hand-in-hand with talking about deep decarbonization targets.

People increasingly believe a clean energy transition is coming and is good; most have no allegiance to tying the economy to the old way of delivering electrons. It is easy to think opponents are villains, but many are just people that have not yet been engaged in a constructive way. Convincing people of their wrongness, however, does not work. The key is to align motivations so they head in the same direction – focusing on outcomes, not motives. Great transitions require trust.

Subnational & Private Sector Action

While deep decarbonization will not be achieved without the U.S. federal government taking a different tack than it is now, local communities around the world, including in the United States, are beginning to drive the climate conversation, setting their own climate goals and plans. This bottom-up action is important. Across geographies and ideologies, climate action is happening in cities, counties, and states.

> While deep decarbonization in the US will not be achieved without US Federal action, states, cities and local communities are now driving the climate conversation.

In U.S. states, there is a growing bipartisan flavor to decarbonization; it is still mostly about shallow decarbonization, but it is at least more bipartisan than at the federal level. While clean energy actions by states such as California and New York have already been mentioned, there has been bipartisan action taken in Michigan, Illinois, Nevada, and elsewhere – not always referencing climate change. The bipartisan governors' accord on clean energy, for instance, does not mention climate change but rather talks about clean energy in the context of opportunity and the risk of consumers paying too much if states do not make the shift. There is a growing ability to work with conservatives around the country on these issues, and there are growing numbers of state and city leaders with appetites for more clean energy and for decarbonizing the grid. Every jurisdiction will figure out what framing and what actions are politically viable. In addition, given how central their involvement in climate mitigation will be, there is an argument being made that cities and states should be able to formally sign on to the Paris Agreement; the old model of nations talking to each other to come to agreements seems out of date.

Private sector action is a growing part of decarbonization as well. Decarbonization of electricity and transportation are fast becoming license-to-operate issues for companies, though the existing framework of disclosure metrics do not really illuminate for investors and stakeholders which companies are really directing capital flows towards a sustainable future. While increasing numbers of private sector players have renewable energy goals, companies need goals on both renewables and carbon. Carbon goals drive long-term decisions and capture things beyond energy purchasing. Renewables goals have more important implications in the near and medium term, as companies seek clean, cost-effective energy that is additional to what is already on the grid in the local environments where they operate. Big companies should continually be asking, though, whether it is faster to reach their greenhouse gas reduction targets by adding renewables or by, say, advocating for keeping the existing nuclear fleet or for deploying more advanced nuclear reactor designs. In addition, although the "social cost of carbon" metric will fall out of favor in the Trump Administration, there is an opportunity for states, utilities, and corporations to step up and incorporate it in their own policies and planning.

China and the Developing World

While the United States is the largest greenhouse gas emitter on a per capita basis, overall growth in emissions and demand growth for electricity place China, India, and other developing nations at the heart of things. Essentially all global demand growth is expected to occur in Asia, Africa, and the Middle East. One of the key questions regarding deep decarbonization, therefore, is whether scaled-up clean technologies will power this demand growth.

This is not a small challenge. Hundreds of millions of people around the world need to gain access to electricity, and many countries are planning to do that with coal. There is thus a dual challenge of increasing the world's energy supply while managing the risks related to climate change to get to deep decarbonization. The world basically needs to bring zero-carbon energy online at the same rate that France did in the 1980s with its nuclear fleet, which was the fastest deployment of zero-carbon energy the world has ever seen. Parts of the developing world may not need the same centralized hub-and-spoke system as the developed world; distributed solar is playing a growing role, though it needs capital. There are other constraints, though, on the growth of clean energy around the world, including land use, availability of rare earths, nuclear waste disposal, and water availability.

In the absence of U.S. leadership on climate action under the Trump Administration, China is often now lionized by environmentalists as a leader in pursuing decarbonization, but there are reasons to be concerned. Opposing the Kyoto Protocol and holding out until the Paris Agreement enabled China to build 1-2 coal plants a week for 20 years. In 2015, China had 9.3 gigatons of emissions, and with its planned build, will soon be at 12 gigatons – locked in place for the next several decades. China's cumulative carbon load will continue to build. While China's thermal capacity factor has been falling every year, and one should not assume that a gigawatt of coal installed will run at a high capacity factor for decades, China is a command economy concerned about output and jobs goals, so it also is not clear that one can count on China not using those plants. In addition to expanding its own coal build, China has been exporting its coal technology as well; there is a programmatic Chinese effort underway to build coal facilities in developing countries around the world.

Some in the United States use pessimistic (or even accurate) views of what is happening in China as an excuse for U.S. inaction. Instead, what is happening in China provides all the more reason for the United States to do its part and develop decarbonization solutions for others. For instance, China will be deploying a high-temperature gas-cooled nuclear reactor, which was American technology. If China is successful in its efforts, it will end up providing that technology to the rest of the world, which will be a missed economic opportunity for the United States.

China is very good at taking ideas and scaling them, but China rarely does the innovation that the United States does. The world will be better off if the United States does not give up on the climate issue, focuses on its innovation advantages, and becomes an exporter of clean technologies around the world

Appendix I: Participant List

Matthew Adams, Chair, Environment and Natural Resources Practice, Dentons LLP
Deborah Affonsa, Vice President, Customer Service, Pacific Gas and Electric Company
Shannon Angielski, Principal, Governmental Issues, Van Ness Feldman
Miranda Ballentine, Former Assistant Secretary for Installations, Environment, and Energy, US Air Force
Roger Ballentine, President, Green Strategies Inc. **(Co-Chair)**
Michael Bates, Global Energy Director, Intel
Michael Bennet, Senator, Colorado
Nazeer Bhore, Manager, Lead Generation and Breakthrough Research, ExxonMobil Research & Engineering
Jacquelyn Birdsall, Senior Engineer, Toyota Motor North America
Bill Brown, CEO, NET Power, LLC
Andrea Hudson Campbell, Partner, Van Ness Feldman
Edward Comer, Professor, University of Pennsylvania Law School
James Connaughton, President & CEO, Nautilus Data Technologies **(Co-Chair)**
Mark Correll, Deputy Assistant Secretary for Environment, Safety and Infrastructure, US Air Force
Ryan Costello, Representative (PA-06), US Congress
Tanuj Deora, Chief Strategy Officer, Smart Electric Power Alliance
Dan Esty, Hillhouse Professor of Environmental Law and Policy, Yale School of Forestry & Environmental Studies and Yale Law School; Director, Yale Center for Environmental Law and Policy
Will Fadrhonc, Lead, Global Energy Policy and Markets, Google
Jay Faison, Founder & CEO, ClearPath Foundation
Patrick Falwell, Senior Director, Green Strategies Inc.
Elizabeth Fretheim, Senior Director, Sustainability, Walmart
Dave Grossman, Principal, Green Light Group **(Rapporteur)**
Gary Guzy, Senior Of Counsel, Covington & Burling LLP
Robert Hallman, Fellow, Center on Global Energy Policy, Columbia University
Bryan Hannegan, President & CEO, Holy Cross Energy
Bruce Harris, Vice President, Federal Government Affairs, Walmart
David Hart, Professor & Director, Center for Science, Technology, and Innovation Policy, George Mason University
David Hayes, Distinguished Visiting Lecturer in Law, Stanford University
Christopher Herbst, Vice President, Government Programs, Eaton
Colette Honorable, Partner, Reed Smith LLP; Former FERC Commissioner
Mitch Jackson, Vice President, Environmental Affairs and Sustainability, FedEx Corporation
Brian Janous, Director, Energy Strategy and Research, Microsoft
James Koehler, Faculty, Georgetown University
Jake Levine, Associate & Policy Advisor, Covington & Burling LLP
Amory Lovins, Co-founder & Chief Scientist, Rocky Mountain Institute
Mark Lundstrom, CEO, Radia, Inc.
Jorge Madrid, Manager, California Clean Energy, Environmental Defense Fund

Brian Marrs, Director, Energy Markets, Microsoft
Thomas Meth, Co-Founder & Executive Vice President, Sales and Marketing, Enviva Biomass
Jeffrey Moe, Global Director of Product Advocacy, Ingersoll Rand
David Monsma, Executive Director, Energy and Environment Program, The Aspen Institute **(Moderator)**
Ronald Nichols, President, Southern California Edison
Michelle Patron, Director, Sustainability Policy, Microsoft
Michael Polsky, Founder, President & CEO, Invenergy
Richard Powell, Executive Director, ClearPath Foundation
Adrianna Quintero, Director of Partner Engagement, Natural Resources Defense Council; Executive Director, Voces Verdes
David Raney, General Manager, Portfolio and Compliance Strategy, Toyota Motor North America
Graham Richard, CEO, Advanced Energy Economy
Bill Ritter, Director, Center for the New Energy Economy, Colorado State University
Kevin Sagara, President, Sempra Renewables
Mark Sanders, Transportation Director, Austin Technology Incubator, The University of Texas at Austin
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Mike Smith, Vice President, Business and Technology Strategy, The Electric Cooperatives of South Carolina
Owen Smith, Director, Utility & Grid Solutions, Trane
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Amy Wagner, Senior Expert, McKinsey & Company
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Appendix II: Forum Agenda

Session I: The Data Room
What are the global and US data from the clean energy sector, how is the deployment of capital signaling momentum and caution, and what is the state of play in policy and political realm?

Moderators: **Roger Ballentine and Jim Connaughton**
Discussants: **Michael Webber**, Deputy Director & Professor, The University of Texas at Austin
Ethan Zindler, Head of Americas, Bloomberg New Energy Finance
Juan Torres, Associate Laboratory Director, National Renewable Energy Laboratory
Jeff Weiss, Co-Chairman & Managing Director, Distributed Sun

Session II: The Transportation Sector – A Tougher Nut to Crack?
The transportation sector accounts for nearly 25% of end-use energy consumption and 27% of greenhouse gas emissions. It is a sector that is nearly 100% fossil fueled and still overwhelmingly reliant on the internal combustion engine. Several countries have announced or are considering aggressive phase out dates for ICE vehicles, and most major auto anufacturers have committed to expanded production of alternative vehicles. Yet in the US, beyond vehicle efficiency standards, there has been relatively little focus on policies to change the fundamentals of transportation technology. Furthermore, unlike the substitution of grid-connected renewables for fossil electricity generation, substituting our incumbent energy sources for transportation with cleaner alternatives involves major changes in consumer products and behavior and will require significant new infrastructure. What should we prioritize and can we move in several directions at once? How are large fleet owners and logistics companies approaching alternative technologies? How does innovation occurring now – such as autonomous vehicles and shared use – align with clean energy and climate goals? Should we rethink our policy approaches?
Moderator: **Roger Ballentine**
Discussants: **David Raney**, General Manager, Portfolio and Compliance Strategy, Toyota
Elizabeth Fretheim, Senior Director, Sustainability, Walmart
Mitch Jackson, Vice President, Environmental Affairs and Sustainability, FedEx
Lynn Trahey, Materials Scientist, Argonne National Laboratory

Session III: Retail Market Disruptions: How Customer Demand and Clean Energy Deployment is Driving Market Disruption
Changing customer demands, increasingly cost-competitive distributed generation, and frustrations with legacy load serving entity offerings are causing bottom-up pressures on traditional utility business models and regulatory structures. In regulated markets, customers feel constrained and are using increasingly complex financial structures to mimic the choice available in competitive markets. In markets with customer choice, an increasing percentage of load is being served by non-IOU/utility LSEs, leading to pressures

on utilities to find new rate-based expenditures and difficult questions on the allocation of system costs. Large energy consumers have led this disruption but new consumer-side initiatives, like community choice aggregation, are broadening the pressures on legacy constructs. How are these developments impacting the energy mix? In regulated markets, how can utilities respond in a way that furthers clean energy while preserving needed revenue? Can we tinker with legacy constructs to accommodate both changing customer demands and clean energy goals or do we need a more radical rethinking of what our retail electricity market should be?

Moderator: **Roger Ballentine**
Discussants: **Graham Richard,** CEO, Advanced Energy Economy
Michael Terrell, Head of Energy Market Development, Google
Ronald Nichols, President, Southern California Edison

Session IV: Deep Decarbonization: Choosing the Right Path and Taking the Big Steps

There is a growing consensus that we will need to achieve dramatic decarbonization in the energy sector over the coming decades to mitigate the worst risks of climate change. There is less consensus, however, as to the paths we should take to get there and the speed at which we must travel. Some advocate a path which prioritizes renewables (primarily wind and solar) in pursuit of a 100% renewables energy sector. Others would equally prioritize nuclear, carbon capture, and other zero emission sources of energy immediately. Still, others believe that natural gas is leading the way in decarbonizing the power sector thus buying time for zero emission technologies to further mature. Intentionally or not, many of the policy choices we have made or that are being considered put us on one of these paths. Which route to deep-decarbonization makes the most sense? What is politicly viable? Are we adequately focused on the demand side? Are we thinking too incrementally and how do we take "big steps"?

Moderator: **Roger Ballentine and Jim Connaughton**
Discussants: **Michael Bennet**, Senator, Colorado
Bill Ritter, Director, Center for the New Energy Economy, Colorado State University
Jay Faison, Founder & CEO, ClearPath Foundation
Nazeer Bhore, Manager, Lead Generation and Breakthrough Research, ExxonMobil Research & Engineering

Session V: Wholesale Market Disruptions: The Struggles of Legacy Baseload Resources, Crisis in Competitive Markets, and the Impacts of State Policy – is Clean Energy to Blame?

Low-cost natural gas, and zero-marginal cost renewable energy are disrupting wholesale electricity markets. Although the Federal Power Act gives the federal government control of wholesale markets, states want to sustain and enhance their say about the energy generation and delivery mix, for example to support renewables, to protect existing baseload resources and jobs (i.e. nuclear or coal), to support new construction and operational jobs, and/or simply to generate additional tax revenues. How does this affect the future of the IPP business model? Should we return to a fully regulated model, finish the job of restructuring to more fully leverage competition and market choice, or are we stuck with the muddle in the middle? Can a path to greater innovation, environmental improvement, and consumer choice be attained in a way that ensures system reliability, security and affordability? What is important near term and long term for a newly reconstituted FERC?

Moderator: **Jim Connaughton**
Discussants: **Brian Marrs**, Director, Energy Markets, Microsoft
Dan Esty, Professor, Yale School of Environment & Yale Law School
Colette Honorable, Partner, Reed Smith LLP; Former FERC Commissioner
Michael Polsky, Founder, President & CEO, Invenergy

Session VI: Life Behind the Meter

Life behind the meter still represents a very consequential and growing opportunity for innovation, energy efficiency, and energy conservation, including through the integration of the stationary and mobile energy systems, development of physical and cyber infrastructure, advances in big data, machine learning, artificial intelligence and automation, and in more productive systems of management, operations and maintenance, and in models for the delivery of goods and services. Because life behind the meter innovation is largely market driven (though often enhanced or impeded by government policy), what are some of the most interesting opportunities before us? What could be a scalable disruption? Where is more, and less, government policy needed to accelerate progress behind the meter?

Moderator: **Jim Connaughton**
Discussants: **Owen Smith**, Director, Utility & Grid Solutions, Trane
Bryan Hannegan, President & CEO, Holy Cross Energy
Mark Correll, Deputy Assistant Secretary for Environment, Safety and Infrastructure, US Air Force

Closing Session: Wrap Up
Moderators: **Roger Ballentine and Jim Connaughton**

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