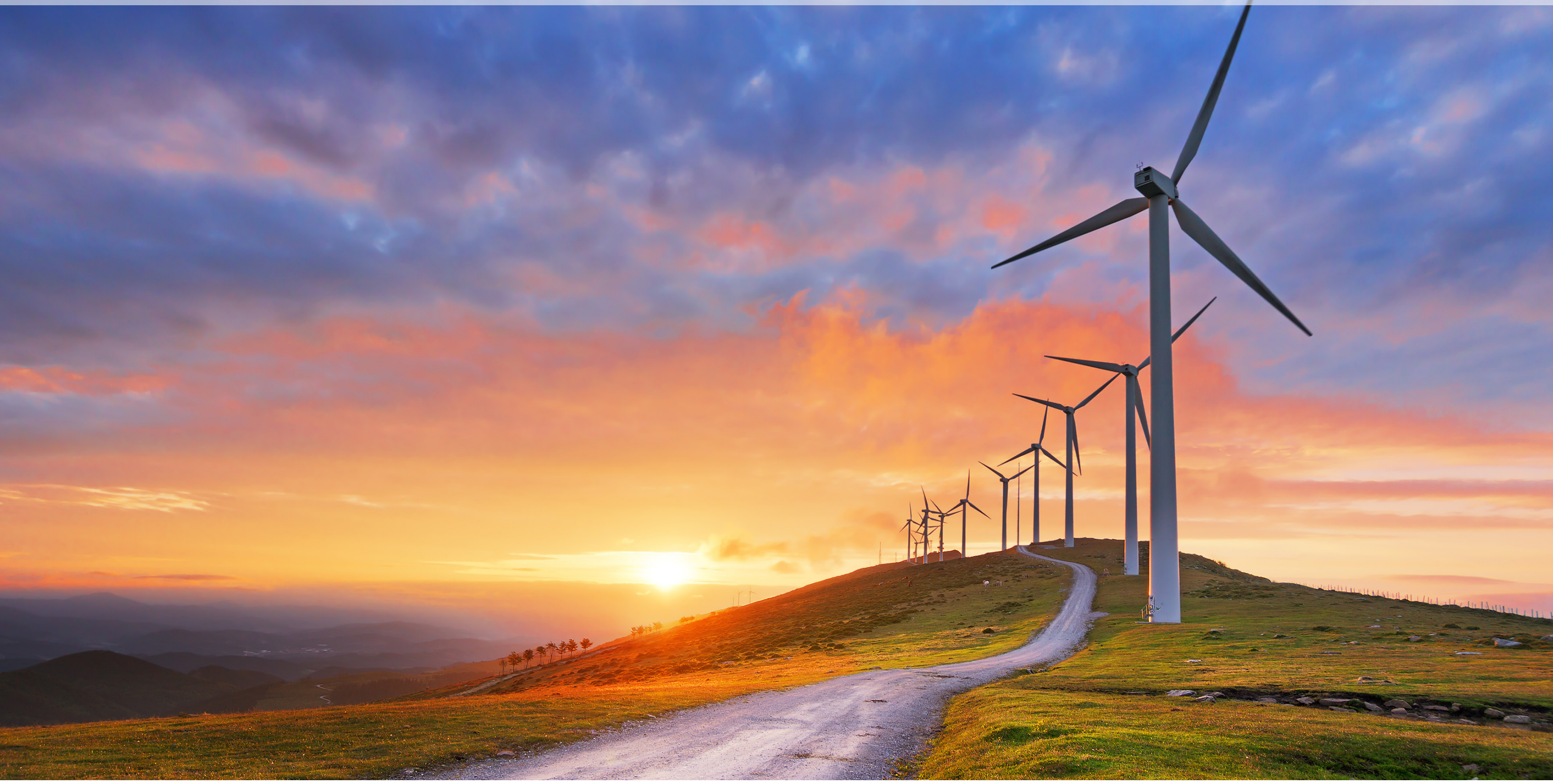
2019 ASPEN ENERGY WEEK



IMPLEMENTING TRANSITIONS FOR THE NEW ENERGY ECONOMY

A REPORT FROM THE
2019 ASPEN ENERGY WEEK

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THE ASPEN INSTITUTE
ENERGY & ENVIRONMENT
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EXECUTIVE SUMMARY

The planet is warming. 2018 was 0.8°C above pre-industrial temperatures, following 2016, which was the warmest year on record. In the United States, as around the world, we are already feeling the impacts – from increased extreme weather like torrential downpours in Houston, to wildfires in California, to droughts and flooding in the breadbasket of the Midwest. We know that the cause of the warming is partly carbon dioxide emitted by the burning of fossil fuels (about 70%), with the remaining emissions from other gases like methane, nitrous oxide, and hydrofluorocarbons, and from sectors like agriculture and deforestation.

What we also know is that if we don't transition to a low-carbon economy as quickly as possible, the impacts of warming will only grow worse, and the first to suffer will be those least able to adapt. In fact, according to climate models, even if we limit warming to 1.5°C, sea level rise will still likely reach one meter by the end of the century – and that is a best-case scenario. Inaction and dissatisfaction with the status quo on climate action and decarbonization have led to a year of movements – from the Fridays for the Future movement to an increased focus from the UN Secretary-General – but action and real leadership from the largest emitters globally are still elusive.

Building zero-carbon generation can prevent further growth in emissions, but it does not reduce emissions unless it leads to the closure of emitting plants.

One reason for the inaction is that achieving deep decarbonization is very difficult, and there is no silver bullet technology or policy that can bring about rapid change. There is, however, a suite of actions that can put the U.S. economy on a path to deep decarbonization.

The sector with the clearest pathway to deep decarbonization is the power sector. In the United States, the grid has been decarbonizing due to a range of factors, including large customers demanding and securing renewable energy. Electric utilities, too, are increasingly getting on board with the zero-carbon transition, though there are still questions about how they will make their bold visions into realities. Many utilities are pursuing aggressive energy efficiency platforms and deploying variable renewable resources, but to achieve 100% zero-carbon, there will have to be some kind of firm, dispatchable, carbon-free power, which could come from a range of sources, including storage, renewables such as hydro and geothermal, nuclear, and fossil fuels with carbon capture, utilization, and storage (CCUS). Building zero-carbon generation can prevent further growth in emissions, but it does not reduce emissions unless it leads to the closure of emitting plants. To accelerate the shutdown of such plants, a path must be devised that addresses stranded assets.

Moving to a low-carbon electricity system will require innovation in market designs and utility business models as well. Incentive-based ratemaking, for instance, could spur utilities to deliver low-cost, reliable, safe, and low-carbon power, rather than getting rewarded based on how much capital they invest. There are numerous other questions about optimal market design as well, such as how to rethink price formation in a low-marginal-cost world and whether and how specific attributes of generation resources – such as flexibility and carbon intensity – should be explicitly valued. Since the fastest transition to low-carbon electricity has been in the most competitive electricity markets, some experts advocate for expanding the competitive model to every region of the country; on the other hand, utilities and customers in regulated systems are generally happy with them, and some regulators want to move away from regional markets due to conflicts with state priorities. Either way, markets also need to allow the increasing number of solar, battery storage, electric vehicle (EV), and other distributed energy resource (DER) users to participate in grid decarbonization.

While the electricity sector is important, decarbonization must extend beyond it and be economy-wide. In the transportation sector, which is currently the largest source of U.S. greenhouse gas emissions, fuel efficiency and electrification can significantly reduce emissions, particularly from light-duty vehicles. Electrification appears to be a less viable large-scale solution in heavy-duty trucking, maritime, and aviation, so development of low-carbon fuel replacements is urgently needed. In the heavy industrial sectors, such as steel, concrete, and glass, there are more limited options for decarbonizing the high heat needed, but hydrogen and carbon capture of process emissions may hold promise with increased research and development.

There are robust debates about whether natural gas is one of the low-carbon fuels that will be needed in hard-to-decarbonize sectors. In the near term, natural gas has been one of the drivers of decarbonization, particularly in terms of displacing coal globally in the power sector, but the near-term impact of natural gas on decarbonization is dependent on the extent of flaring and methane release that occurs. In the long-term, the expected boom in gas production and exports is in conflict with meeting climate targets. In addition to electrifying some end uses, potential ways to replace natural gas in existing infrastructure could include renewable natural gas (i.e., biomethane) and hydrogen. While natural gas is often used for heating, cooling buildings presents its own climate conundrum: on the one hand, air conditioning globally will use growing amounts of energy and release hydrofluorocarbons, but on the other, there is a moral obligation to provide cooling to people in a warming world.

Achieving deep decarbonization, particularly in hard-to-decarbonize sectors, will require technological breakthroughs, which means innovation is critical.

Achieving deep decarbonization, particularly in hard-to-decarbonize sectors, will require technological breakthroughs, which means innovation is critical. There are numerous pinch-points, however, in moving technologies from idea to commercialization. Potential ways to advance low-carbon technology demonstration and deployment include establishment of a technology deployment leadership council that exposes company CEOs to emerging technologies and creation of a quasi-governmental corporation to advance low-carbon demonstration projects. In addition, digital technologies will play essential roles in enhancing capabilities and reducing transaction costs, but the availability of digital technologies needed for climate-related innovation will be contingent on the actions of regulators outside the realm of energy and environment, such as those involved in regulating artificial intelligence, export controls, drones, and spectrum. Combined, technological innovation and digitalization can undergird the trend towards smart cities and connected communities, which seek to modernize physical, digital, and social infrastructure to deal with both decarbonization and the explosive rate of change in global urbanization.

Decarbonization will also require accelerating the flows of capital into low-carbon solutions, which could be advanced by incorporating climate risk and carbon value into the economics of deals, the valuation of enterprises, and the return profiles of investments. In addition, governmental finance mechanisms can de-risk the flow of private capital and guide it into green solutions. Applying environmental factors in bond ratings could be an additional way to integrate environmental and carbon risks. There are a lot of financial resources in both the public and private sectors that can be brought to bear on decarbonization, but private-sector actors, including investor-owned utilities, are looking out for their shareholders, not just the needs of customers and society. Legal and regulatory changes and shareholder pressure may be needed to expand notions of fiduciary responsibility to include investments in low-carbon solutions.

The significance of any technology for deep decarbonization, though, will be proportional to the extent it is traded from where it is developed to where it has to be used; global deployment of technologies requires trade. Clean energy technologies and their components have different types of global trade networks and flows, with China often being dominant, though the United States has some strengths and opportunities as well. The U.S. industrial sector, however, is losing out on opportunities because, unlike China and some other countries, the United States has not chosen to make a big industrial policy push. In any decarbonization scenario, policy tools such as border adjustments will be needed to protect energy-intensive industries and avoid outsourcing emissions.

Policies provide the external sideboards and direction for finance, trade, markets, and private-sector action. In designing climate policies at any level of government, it is important to think carefully about effective incentives, linkages among issues, the importance of innovation, and other factors. One of the clearest financial incentives for decarbonization is a carbon price, but the prices proposed in potential legislation are often far too low to be tech-shifting (except in the electric power sector) or to achieve climate targets on their own. To be most effective and efficient, a price on carbon would likely need to be part of a larger suite of decarbonization policies – ideally a suite that is strong, simple, and coordinated, as opposed to the complex and conflicting thicket of federal, state, and local mandates and incentives that now exists.

Legal and regulatory changes and shareholder pressure may be needed to expand notions of fiduciary responsibility to include investments in low-carbon solutions.

There have been some promising policy trends in the United States. At the subnational level, growing numbers of people live in a community, city, or state that has committed to 100% clean energy. At the federal level, climate change is becoming a less polarized topic, which opens the door for discussions with a broader set of stakeholders and policymakers. To be successful in that context, climate policy has to be legislatively realistic, politically sustainable, and effective in actually solving the global emissions problem. Coalition-building will be vital. Some would argue that political economy suggests a need to include the fossil fuel industry in the coalition, as well as small- and medium-sized businesses, though different types of coalitions can achieve different objectives (e.g., legislative action versus outside activism to change the landscape of what is possible).

One clear change driven by outside coalitions has been the incorporation of indelible social justice and workforce elements in the conversation around climate change. This includes greater attention to the effect of climate policies on energy costs, but the equity issues are much, much broader. The energy sector alone cannot address the existing systemic inequities (e.g., job insecurity, income inequality), but it should be careful not to exacerbate them. It is important to ensure that the benefits of the low-carbon transition are widely shared, which requires intentional policy. It is likewise important to figure out how to drive investment to places where workers and communities are likely to otherwise suffer because of the low-carbon transition.

There are also very pressing issues related to the impacts of climate change on people and communities. Increasing the resilience of power grids to stronger storms will involve hardened systems and greater modularity, as well as green infrastructure. Resilience challenges for the grid will only become more acute as other sectors electrify. Wildfires, meanwhile, are increasingly severe and damaging in the West. In California, utilities' wildfire mitigation plans tend to focus on vegetation management, system hardening, and proactive power shutoffs during dangerous conditions, but the plans tend to pay little or no attention to the value of DERs for resilience. The fires, storms, floods, and other disasters and changes have made clear to people that climate change is not just about effects on children and grandchildren in the future but is also about now and us. Congressional attention to such impacts and the need to strengthen infrastructure can be an on-ramp to bipartisan engagement on climate issues.

DECARBONIZING ELECTRICITY: TRENDS & TECHNOLOGIES

Humanity is nowhere close to achieving the kinds of greenhouse gas emission reductions that science says are necessary. Indeed, global emissions of carbon dioxide (CO2) and other greenhouse gases are still rising. There is near consensus, though, about what needs to be done to achieve deep decarbonization. The basic steps include maximizing energy efficiency, decarbonizing the grid, electrifying other sectors to the extent feasible, deploying zero-carbon fuels in harder-to-decarbonize sectors, and figuring out how to scale up deployment of carbon capture, utilization, and storage (CCUS), carbon dioxide removal from the atmosphere, and other negative-emissions technologies. An additional element involves addressing non-CO2 greenhouse gas emissions, such as methane and hydrofluorocarbons. These steps are not sequential, but rather must occur in parallel.

While the steps are known, how to actually carry them out is not. The sector with the clearest line of sight to deep decarbonization – and the one that can drive decarbonization efforts in some other sectors – is the electric power sector.

INFLUENCE OF LARGE BUYERS

The grid has been decarbonizing due to a range of factors, including natural gas replacing coal, plummeting costs for renewables, and supportive state policies, but a sometimes overlooked driver has been large corporate buyers and municipal customers demanding and securing renewable energy, principally wind and solar. Large corporate energy consumers have been pushed by social, political, customer, and investor pressures, as well as by internal pressures from employees and leadership.

There is increasingly an economic case to be made for these efforts as well. Wind and solar prices are at historic lows, and there are lots of grids where companies can do power purchase agreements (PPAs) at prices below what they are already paying. It is not hard for people within companies to go to their Chief Financial Officers for a renewables PPA. They not only pencil out, but they are also fixed price contracts, which avoid price swings and give companies certainty.

Many companies have made commitments to achieve, or have already achieved, the status of being powered by 100% renewables, which means they have procured enough renewable electricity to match their total electricity consumption. It does not mean that they are actually being powered by renewably generated electrons all the time, in all locations. Some companies are looking to achieve 100% zero-carbon energy 24/7 for all operations, but they have no idea how to actually achieve it. For instance, for some big tech companies, adding wind, solar, batteries, and load optimization to the existing grid supply might get a particular data center into the 80-90% zero-carbon range (and all of that may not be cost-effective), but how to actually get to 100% for all sites at all times is very much an open question. It will require decarbonizing the grid overall; if the grid is green, corporations that want to rely on 100% zero-carbon electricity would have a much easier time of it.

Until then, corporations that want to green their power supplies have to make deals. The problem is that the current convoluted approaches to securing these deals are not scalable. The corporate demand is there, but barriers need to be broken down in order to scale. For instance, individual companies have had to pursue changes in policies, regulations, and transactional mechanisms to enable them to directly purchase clean electricity at all. Only large, sophisticated companies will invest in making those changes. Small to medium-sized businesses, in contrast, are often tenants and are non-investment grade, so they generally have very limited access to wholesale markets; if they are looking to fully decarbonize their operational loads, they will have to rely on utilities to offer more retail products. There is work underway to break down some of these barriers more systematically for all corporations.

Large energy buyers could increase their decarbonization influence by expanding their field of vision. For one thing, large buyers of renewables could look at the energy system as a whole instead of just at electricity, such as by overbuilding renewables and using the excess generation to produce zero-carbon hydrogen. Large buyers could also expand the portfolio of zero-carbon options they procure, but that may require fixing the existing accounting standards that currently drive them primarily toward wind and solar.

As it is, companies seeking zero-carbon energy have been very influential in driving the behavior of electric utilities, who want to meet the demands of their customers. As more companies (and others) push for zero-carbon energy and adopt 100% clean energy commitments, utilities will feel even more pressure to meet those customers' needs.

UTILITY STRATEGIES

There has been an incredible amount of progress over the past few years in utility planning to achieve a low-cost, customer-empowered, clean energy future. Some have never seen as much change in the utility industry as is occurring now. Utilities are increasingly getting on board with the zero-carbon transition. The mindset and investment strategies in the electric utility industry have changed, with full recognition of climate change as an issue. Over 300 U.S. utilities have established clean energy or carbon commitments, with over 40 setting carbon-neutral, net-zero, or carbon-free goals. Even a couple of years ago, discussions in utility board rooms were not focused on climate change, but now they are. The drivers behind this shift include pressure from customers (especially large commercial and municipal customers), pressure from investors, the rapidly declining costs of new technologies, and new priorities set by climate scientists.

Storage deployment in the United States has already been growing significantly, and more than half of states have work underway to look at how to change distribution system planning processes accordingly.

While utilities are putting forth bold visions, there are still questions about how they will make them realities. Decarbonizing the power sector is easier than other sectors, but it is still not a light lift. Clean energy solutions and decarbonization pathways will also vary dramatically by region, as the costs, technologies, and existing baselines are all very different. In the North Central and Mountain regions of the country, the largest electricity resource is currently coal, whereas it is natural gas in most of the rest of the country and hydro on the Pacific Coast. Nuclear is the second largest resource in the regions in the eastern half of the country. Non-hydro renewables only manage to achieve even a moderate scale in a few regions.

To achieve a decarbonized grid that is reliable, resilient, secure, adaptable to customer choice and distributed energy resources (DERs), and prepared for the increased demands on the grid from electrification of other sectors, utilities should invest in the physical asset base (e.g., wires, poles, substations, digital communications), system operations and planning (e.g., DER management systems), interfaces with customers (e.g., marketplaces), and perhaps transactive energy exchanges to allow for peer-to-peer customer interactions. With growing renewables and a transition from a centralized system to a system that has a mix of centralized and distributed assets, there is a pressing need to figure out what utilities' roles and responsibilities are, what their earning streams are, what the implications are for their relationships with customers, and what the implications are for distribution system operations. While many utilities can operate well under the existing model of being sellers of kilowatt-hours for quite a while, there will ultimately need to be a business model transition. Utilities, utility commissioners, and commission staff will have to try to obtain and act on good data in a world where more customers are demanding greener energy and more control and where technology is changing at a very rapid pace.

Integration of those technologies into the grid will require attention. Getting beyond something like 80% renewables will shift utilities' focus from procuring least-cost resources to procuring resources that fill in peaks and valleys in utilities' load profiles. There will be a need for more flexible, and potentially more expensive, dispatchable zero-carbon options, including energy storage and responsive loads. Storage deployment in the United States has already been growing significantly, and more than half of states have work underway to look at how to change distribution system planning processes accordingly.

Getting to deep levels of decarbonization in the sector would also be easier if power providers could coordinate and link their efforts to low-carbon fuel production, hydrogen production using excess renewables, or electrification of other sectors, all of which could change the economics of their investments. Some utilities are indeed exploring options under such an expansive systems perspective, but more public and private research and development (R&D) should focus on opportunities at the intersection of sectors.

ENERGY EFFICIENCY & CONSERVATION

Many utilities are pursuing aggressive energy efficiency platforms in their jurisdictions. Utility-funded energy efficiency programs saved almost 200 terrawatt-hours of electricity in 2017, more than double the savings from a decade earlier. The most progress has occurred in states that have adopted energy efficiency resource standards, decoupling, or other such policies. With demand growth rates that are flat at best, though, utility investments in efficiency programs, rebates, retrofits, and the like are reducing their base of consumption.

Regulatory innovation is needed to move to an emission performance standard or a carbon reduction standard, so entities can be measuring what actually matters.

There are many barriers to maximizing energy efficiency. Costs are one. For example, efficiency often is relatively underfunded, even when there is a return on investment, because the capital hurdle rate is sometimes too high. Similarly, as wholesale rates are coming down, it is harder for some energy efficiency programs to pass the required cost-effectiveness tests. There can also be resistance from industrial companies and low-income customers to paying fees that support efficiency programs that pay for someone else's energy efficiency measures.

The structure and positions of the real estate industry are another obstacle to greater efficiency. For example, Americans shopping for a home do not get transparency and disclosure about energy costs because the industry does not want it. A termite inspection is required for every home but not disclosure of the greatest operational cost of a home. In addition, more and better efficiency programs are needed to address the needs of commercial tenants or residential renters in multi-family buildings – people that move, cannot install equipment, and may not always pay for energy usage. Making sub-metering and energy auditing mandatory for commercial real estate, for instance, could make a difference.

Thinking differently about energy efficiency can help as well. For example, even when utilities offer free energy audits to all residential customers, very few customers ask for them. There is a need to rebrand energy efficiency to focus on products and experiences that consumers want that can help with decarbonization and grid flexibility. There is also a need for a separate emphasis on energy conservation – apart from energy efficiency – that can refocus attention and effort on the many things that are now done with electricity (e.g., a sensor to dispense paper towels) that could be done mechanically. Moreover, energy efficiency standards need to be rethought in light of the carbon-reduction imperative. Energy efficiency is usually in regulatory codes as an electricity load reduction standard, but that assumes all electricity is uniform and bad, which is not the case with a decarbonizing grid and a push to electrify other sectors. Regulatory innovation is needed to move to an emission performance standard or a carbon reduction standard, so entities can be measuring what actually matters. California, for instance, approved using energy efficiency funds for fuel switching, such as displacing natural gas appliances.

DISPATCHABLE, ZERO-CARBON POWER

While an important part of the solution, humanity will not combat climate change with energy efficiency alone. The core need is to take carbon out of the system; once the electricity supply is decarbonized, energy efficiency in the power sector will do little to lower emissions. There is growing consensus among academics and others that an approach that relies solely on variable renewables is not the way to maximize opportunities and the timeline for decarbonizing the power sector. Renewable energy is a great tool, but it is not the end in itself; the end is decarbonization. Variable renewables can be a big part of the picture and can hit pretty high levels of penetration before systems issues start to arise, but at some point on the drive to 100% renewables, systems costs would get much higher, and there would be huge amounts of over-generation.

Renewable energy is a great tool, but it is not the end in itself; the end is decarbonization.

To achieve 100% zero-carbon, there will have to be some kind of firm, dispatchable, carbon-free power, which could come from a range of sources. Even if some of the potential technologies currently seem pretty far away, there will be a need for them, and there are lots of options out there to work on and try. An innovation agenda is needed to make more low-cost options available; doubling or tripling the R&D budgets on those options might spur greater progress.

Storage

Storage can make variable renewables dispatchable. Battery storage has been booming, but it is still too costly in some applications. For instance, a tiny fraction of the houses with rooftop solar also add battery storage, as it is largely uneconomic in many places (though it depends on the place and on the available incentives). Batteries also have far shorter lifespans – and therefore require far more frequent replacement – than some of the multi-decadal assets (e.g., gas peaker plants) they are poised to replace. Batteries will continue to get better, though, which will be vital as they are called upon to do more.

There are storage options besides lithium-ion batteries that are sometimes overlooked, including flow batteries, pumped hydro, compressed air, liquefied air, mechanical storage technologies, and thermal storage. None of these are easy, some are still in very early days, and all need to see big cost drops, but much greater storage capacity and many more storage options will be needed to firm variable renewables.

All of the storage technologies have time constraints. The storage problem has largely been solved for a few hours' worth of storage, but not for storage on the order of days, weeks, months, or seasons. Lithium-ion batteries are roughly 4-hour resources; they are not a credible multi-day storage option. Neither is pumped hydro (or pumped anything), which offers storage more on a day timescale than on a months timescale. Hydrogen could provide a seasonal storage option, but again, it is still in its early phases.

Dispatchable Renewables

Renewables are more than just wind and solar. Hydro, for instance, is dispatchable and has some interesting potential in North America. On the other hand, hydro capacity factors are pretty low (only around 40-50%), there is seasonal variability in water volumes, and it is increasingly difficult to forecast hydro availability (e.g., volume of snowmelt).

There are also other renewable technologies worth paying attention to, including airborne wind and advanced geothermal. The deep geothermal resource in the United States is substantial and largely unused, though there is lots of research on how to cost-effectively tap it.

CCUS and Direct Air Capture

Coal and gas plants are being built around the world, and the emissions associated with that multi-decadal infrastructure will be enormous if not addressed. For that firm, dispatchable power to be zero-carbon, CCUS will be needed. For example, a study looking at emission reduction potentials by sector in the California economy to achieve the state's 2030 targets found the largest opportunity in the electric power sector was natural gas combined cycle plants with CCUS (followed by renewables with 10-hour storage).

The recent innovation on carbon capture has been profound, and costs are dropping quickly. More will be known about costs and performance soon, as new technologies are tested and scaled. New technologies hold the potential to be cheap and easy to execute, both for retrofits and new build.

CCUS is only part of the carbon capture picture. It is a tautology that to have "net-zero emissions", negative emissions will have to be achieved.

Costs matter if the goal is to preserve affordability of power. A natural gas plant could be retrofitted with carbon capture technology today and deliver zero-carbon power at a lower cost than community solar. That is on a cost basis, though, not a finance basis, so actually deploying the technology and factoring in the cost of permits, land for sequestration, and the like suggests the delivered cost would be higher. Things like the cost of permitting and characterizing the geology, among other factors, put the costs of a really good natural gas retrofit at something like $80/ton. Currently, the 45Q tax credit does not matter much at all for the power sector because the math for CCUS in the power sector does not pencil out at $50/ton. There has to be some kind of adder to get capital markets interested, though how big the adder needs to be and how long it needs to last to clear the investment hurdle rate are still to be determined. In addition, repurposing the trillions of dollars of existing fossil fuel infrastructure (e.g., wells already drilled) for carbon sequestration could improve the economics, and the idea is starting to gain a bit more attention. For instance, some projects have found that avoiding the cost of dismantling offshore platforms by using them for CO2 storage greatly improves the return on investment.

Beyond the cost of CCUS technologies, there are also public acceptance questions. To be net-zero in 2050, the amount of CO2 that CCUS technologies will have to transport and put underground will be staggering. An industry and infrastructure as big as the oil industry (or bigger) will have to be built to manage that. This is not to say it cannot be done, but it is critical to think about what the public acceptance will be of something like that. Not-in-my-backyard (NIMBY) passions can run high when the rubber meets the road on CO2 pipelines and underground storage, which may be why most current CO2 storage (that is not enhanced oil recovery, or EOR) occurs in the North Sea, where there are no NIMBY issues. Regulatory innovation is needed as well, such a liability regime for carbon dioxide stored underground.

CCUS is only part of the carbon capture picture. It is a tautology that to have "net-zero emissions", negative emissions will have to be achieved. Direct air capture (DAC) – which captures CO2 from the atmosphere – will likely be one critical technology for achieving negative emissions. DAC is on a similar trajectory to CCUS. Costs are coming down, and by 2025, DAC costs could be below $200/ton, though that estimate is not universally accepted. If federal money is put into scaling DAC, costs could be driven down faster.

Nuclear

The dialogue around nuclear power has started changing, with greater recognition in the policy and corporate worlds that the firm, zero-carbon power provided by nuclear will likely be needed to achieve deep decarbonization. For instance, several states have adopted 100% zero-carbon – not 100% renewable – targets, and the Green New Deal resolution speaks about "clean" energy and zero emissions, leaving a potential role for nuclear.

Nuclear power is currently the largest source of carbon-free generation in the United States, but many U.S. nuclear plants are financially stressed and facing closure, due in part to wholesale power markets.

Nuclear power is currently the largest source of carbon-free generation in the United States, but many U.S. nuclear plants are financially stressed and facing closure, due in part to wholesale power markets. Wholesale power prices were higher 10 years ago, dropped during the recession, and are now about half of what they were a decade ago. The cost of operating the nuclear fleet has dropped by about a quarter, but that is not enough to fully counteract the drop in prices. If existing nuclear plants are not protected, it will take years for renewables and other sources to fill the zero-carbon hole created, making the climate problem even harder to solve. Some states, such as New York, Illinois, New Jersey, Connecticut, and Ohio, have taken steps to stop the closure of existing nuclear plants. In four of those states (all but Ohio), the carbon-free attribute was valued, and those plants are no longer at risk of being closed. Properly valuing the attribute – whether through a clean energy standard (CES), a carbon adder in wholesale markets, or other means – should be enough to keep most existing nuclear plants in the market (though it would not spur much new build).

There were no new nuclear reactors built in the United States in the 1990s and 2000s, and there was only 1 in the 2010s, but the 2020s may be very different. Some foresee 20 advanced nuclear reactors of different kinds being built in the United States, and many other countries are interested as well. Advanced nuclear is not currently competitive, but when it becomes ready to deploy in a decarbonizing system, it is a more open question as to what advanced nuclear will be competing against. By the end of the 2020s, it will be known if advanced nuclear is a real option.

STRANDED ASSETS

Building zero-carbon electricity generators can prevent or reduce further *growth* in emissions, but it does not *reduce* greenhouse gas emissions unless it leads to the closure of emitting plants. In some competitive markets, the market is pushing out coal plants due to the low costs of natural gas and renewables. In regulated arenas, there are some efforts to speed up their closure, such as by accelerating depreciation. Some utilities used their gains from the federal tax reform law to accelerate depreciation of some coal units.

The velocity and timing of closing plants early really matter. Closing plants early helps the atmosphere a lot, but it can come at a cost to taxpayers, ratepayers, and plant owners. For instance, there are many relatively new fossil fuel plants in operation in the United States (and around the world), which will not be shutting down any time soon. Owners still owe millions of dollars on those assets, and some installed billions of dollars' worth of scrubbers on coal units within the past decade. If the aim is to shut down those emitting plants, a path must be devised that figures out how to pay for the shutdowns. It is important to figure out how to deal with stranded assets, as well as stranded workers and communities.

There have been prior national policy models to address stranded assets, and when the changing of the regulatory bargain came with the ability to recover stranded costs, the affected industries largely got behind the transition. A balance must be found, however. Those that invested in those plants made a decision that had risks, and they presumably got an economic benefit out of the plants while externalizing other costs onto society, so full bailouts for stranded assets may not be warranted. The picture may be murkier for public power entities, though, where it is the customers and communities who own the assets.

CCUS is only part of the carbon capture picture. It is a tautology that to have "net-zero emissions", negative emissions will have to be achieved.

DECARBONIZING ELECTRICITY: MARKETS

Electricity markets are moving into a more complex, more innovative, more interesting time. Moving to a low-carbon electricity system will require a lot of innovation – not only in technologies, but also in market designs, utility business models, and more.

MARKET DESIGN

A lot of things are running ahead of and driving change in current electricity market and regulatory structures, including new technologies, DERs, two-way power flows, cyber risks, low natural gas prices, and the increased intermittency of supply as zero-marginal-cost renewables move from niche to mainstream. The current system is not quite up to the job. States and other jurisdictions are basically trying to maximize the value of particular technologies or address the shortcomings of others with a system that was not designed to do that, and it is not working particularly well. Capacity markets, for instance, are not working well for battery storage. There could be a lot more wind and solar if there was a more national grid that enabled power to be wheeled around the country, but there is currently no market structure to enable that. Some therefore advocate stepping back and exploring the possibility of starting over, such as with a federal advisory committee tasked with looking at these issues and formulating significant recommendations.

Utilities should be incentivized to deliver low-cost, reliable, safe, and low-environmental-impact energy

Some argue that the most important thing regulators should do in reimagining electricity markets is to incentivize monopoly utilities to do things beyond just put steel in the ground. They are still putting steel in the ground, even in situations where demand is not growing, because they are rewarded based on how much capital they invest. Instead, utilities should be incentivized to deliver low-cost, reliable, safe, and low-environmental-impact energy, and the state regulated model can be one good way to drive that, as that is where the capital is coming from. Incentive-based ratemaking can push utilities to boost distributed energy resources and therefore reduce transmission and distribution costs. In New York, for instance, Reforming the Energy Vision (REV) is working well in terms of incentivizing utilities to pursue non-wires solutions. Utilities could also be incentivized to increase capacity utilization. The grid is designed largely to meet the needs of a few hours in July and August, which means capacity utilization overall is fairly low. Incentivizing capacity utilization will increase the capital efficiency of the sector and so will also make power more affordable and accessible to all. Incentive-based ratemaking could bring the pressure of competition, keep the low cost of financing, and compensate utilities for helping to solve the problem.

There are numerous other questions about optimal market design as well. For instance, there are questions as to whether scarcity pricing (as used in ERCOT) or capacity markets (as used in PJM) better incentivize long-term capital investment. There are also different approaches to bringing in demand-side services and demand response as resources to balance supply and demand, with many different market-based solutions in different places.

In addition, there are fundamental interplays between the design of electric power markets and the design of carbon and clean energy policies in terms of which factors drive resource decisions. For example, under a 100% clean energy standard, as the amount of clean energy approaches 100%, the value of the clean energy certificates dominates the compensation for power provision, while energy market prices are driven towards zero. Similarly, a carbon adder tied to the social cost of carbon (around $50/ton) will end up driving the price of renewable energy certificates to zero; the carbon adder will become the rationalizing force. Balancing supply and demand in these worlds would be very different from now. Thought would also have to be given to what happens to the stranded generation assets.

One of the core challenges may be that the conceptual economic foundations of market design are missing for a low-marginal-cost world. Locational marginal price (LMP) is based on marginal cost being positive, which will not necessarily always be true. Price, for instance, could be negative because of oversupply. There is a need to rethink price formation theory in that context.

The lack of a fundamental theory of price formation at the distribution or retail level is particularly problematic as the pricing signal becomes more dynamic. The price at a given location at a given time will be the LMP at the nearest wholesale node plus some set of terms (e.g., congestion, frequency, voltage, environmental attributes). If a fundamental theory of price formation could be enabled, it would give utilities that want to be distribution system operators (DSOs) the sense that they can add another term to that equation: the cost associated with transacting on their distribution system, as they still have to recover what they spend to maintain the infrastructure. If utilities cannot add in a term to ensure financial adequacy and have confidence in a new theory of price formation, they will fight hard to stick with the cost-of-service model because it pays the bills.

VALUING ATTRIBUTES

Whether and how specific attributes of generation resources – such as flexibility and carbon intensity – should be explicitly valued is a central debate at the moment. In PJM, for instance, there are real-time and day-ahead power markets, ancillary services markets (e.g., for ensuring frequency regulation), and locational marginal pricing to reflect congestion in transmission – but there is no regime for pricing carbon or for addressing fast-ramping capabilities There may also be other attributes to work into markets going forward, such as reliability. On the other hand, a balance must be struck between the desire to include values for multiple attributes and the desire of those actually working to develop zero-carbon energy projects for simplicity. Rather than creating complicated systems, such as New York's value of distributed energy resources (VDER) – which layered many different elements into the value stack and then added more levels of complication – things work better when they are simple and capital markets can finance them.

The failure to price in resources' carbon attributes has meant that zero-marginal-cost competition is making it hard for existing nuclear plants to be competitive in some markets.

The failure to price in resources' carbon attributes has meant that zero-marginal-cost competition is making it hard for existing nuclear plants to be competitive in some markets. The failure has also meant that policies and markets have been driving massive renewables deployment without consideration of climate change; they do not, for instance, capture whether a megawatt of clean generation is competing against a polluting resource or a zero-carbon resource. Something like a carbon adder can start to bring policies and markets together to achieve emission reductions. Some argue that FERC has authority under existing law to determine that the absence of a price on carbon is a rate-affecting practice that is discriminatory, unjust, and unreasonable – and so has the authority to set a price on carbon in all regional markets under existing law – but others disagree.

EXPANDING OR RETREATING FROM COMPETITIVE MARKETS

Empirically, the fastest transition to low-carbon electricity has been in the most competitive electricity markets where restructuring occurred reasonably well. Only a subset of the country has electricity markets, but some experts advocate for expanding the competitive model to the whole country. They argue that creating a regional transmission organization (RTO) in every region would bring savings for consumers and improved ability to manage the intermittency of renewables. FERC has the authority to require an RTO in every region, but it has not exercised it.

This vision is part of a larger argument that the current wholesale/retail and federal/state splits are not serving the needs of moving toward a low-carbon future. The current state-by-state structure is an anachronistic legal fiction that was designed many decades ago when utilities were all vertically integrated and retail sales were most of what they did, but that is not the situation anymore. Power is one of the most inherently interstate of products, and it is worth asking how it is that systems arose in the United States in which gas molecules are fungible across the nation but electrons are not. Instead, backed by an overriding national policy (e.g., price on carbon, clean energy standard), there could be regional market platforms in every region of the country, which all retail customers could buy into and that all demand response providers could participate in. The regulation of distribution wires would still probably be left to the states, owned and operated by wires companies (though there could be regional distribution system operators that aggregate distribution systems the same way that RTOs have done for transmission). Everything else beyond the minimal scope of a monopoly franchise would be opened up to competition. The system would be plug-and-play, with all possible suppliers, providers, and technologies that comply with the market rules allowed to enter to serve the market.

On the other hand, it is not clear what would drive big regulated utilities to move to a more competitive wholesale generating system across more of the country. Utilities and customers in regulated systems are generally happy with them, and some states have essentially re-regulated and moved back to integrated resource planning (e.g., by mandating specific amounts of solar, batteries, or other resources). Regulators in some states want to move away from the RTO model due to conflicts between RTOs and state policies. Regulated utilities also have more leeway to pursue big R&D programs and take risks on controversial projects because the risks are socialized and built into the regulatory structure.

In addition, regionalization has the potential to undermine state climate leadership by allowing for imports of dirty electrons from other states that are not on the same page. Relatedly, regionalization could face governance issues in some regions. In the West, for instance, many states might not appreciate an 800-pound gorilla like California dominating the RTO governance – and, conversely, California would not appreciate dominance by other states. States also want the jobs and economic growth from the move to a 100% clean, decarbonized grid to be in their states, which would be more complicated with regional designs.

Rather than trying to reinvent everything in a grand, integrated system, there may be a need for common national objectives that are addressed in very different systems. The United States has multiple systems that have grown in different ways in different geographies, and there may not be one panacea that applies to all.

CUSTOMERS AND DERS

Markets need to allow the increasing number of solar, battery storage, electric vehicle, and other DER owners/users to harness how they use, generate, store, and conserve energy and to participate in having an aggregate impact on grid decarbonization, affordability, reliability, and resilience. The current era is one in which some consumers want to be treated as equal partners in the process of decarbonization and in providing grid services. This requires some changes in markets. Many jurisdictions, for instance, could get better at integrating DERs into distribution system planning, and it is not happening at all in some regions. As an example, many U.S. jurisdictions have not really contemplated solar-plus-storage systems before, so those interconnection rules and procedures need to be updated. The potential convergence of electro-mechanical and digital communications networks could allow owners/users of such technologies to benefit from changes in prices and the bidirectional potential of battery assets. Utilities have an important role to play, but it is also important to have a regulatory framework that encourages consumer choice and competition among market participants.

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While some customers are pushing for choice and the ability to control the details of their energy lives, it must be remembered that all customers are not the same, especially residential customers. Many could not care less and would prefer not to have the complication. Some care about price, and some want to be greener, but not many customers have the appetite to learn, engage, and get into the weeds. Different customers have different objectives, and they need to be given choices that correspond to their objectives – whether bill savings, green energy, or never being without electricity. Many customers would be happy to benefit but have no interest in being empowered or involved, so if choices are tech-enabled in an easy way, then people's choices can be simply set and automated. The technology also exists to aggregate those choices, though the frameworks, regulations, and compensation methods for such aggregation are often lacking.

In addition, it is worth recognizing that if a policy is adopted to achieve a 100% zero-carbon grid, then from a climate perspective, it would not matter what choices customers make, what options they are given, or which customers are able to participate.

DECARBONIZING OTHER SECTORS

Discussions around decarbonization tend to default to discussions about the electricity sector, but decarbonization has to be economy-wide. In the United States, emissions from electricity account for about 27% of total emissions, leaving another 73% to grapple with. The economic feasibility, technical feasibility, and practical feasibility of eliminating a ton of carbon are radically different across different sectors of the economy. While unquestionably challenging, the electricity sector is far easier to decarbonize than other sectors; the power sector is not the heavy lift.

Eliminating all emissions from harder sectors such as transport, heavy industry, and buildings may not be possible, though, which is where CCUS, afforestation, and other measures to achieve negative emissions will be needed.

Deploying low-carbon electricity and fuels in other sectors will be an essential part of economy-wide decarbonization. Eliminating all emissions from harder sectors such as transport, heavy industry, and buildings may not be possible, though, which is where CCUS, afforestation, and other measures to achieve negative emissions will be needed.

TRANSPORTATION

Transportation is currently the largest source of U.S. greenhouse gas emissions. In some ways, decarbonizing the transport sector might be easier than the electric power sector, as there are only a handful of large manufacturers on the heavy-duty side and maybe just over a dozen on the passenger side. When regulations are set, there are therefore not many actors in the industry to corral. On the other hand, transportation is hard because of all the individual choices involved.

In terms of personal, light-duty transport, fuel economy standards do far more than electric vehicle (EV) policies to reduce oil demand and emissions, at least in the near term. For instance, a study looking at emission reduction potentials in California found that the largest opportunity in transportation (indeed, the largest in any sector) came from light-duty vehicle efficiency standards, followed by the light-duty low-carbon fuel standard. Electrification of passenger cars is also vital – and advancing. Companies are deploying EV charging stations at their facilities for employees and, for retailers, at their stores for customers. Retailers are competing to put in the most and the fastest chargers, not only because of image but because people may buy more in the store when waiting for their cars to charge.

Likewise, many electric utilities see beneficial electrification of other sectors as a key path for the industry moving forward, and EVs are where many are starting. Utilities in several jurisdictions are aggressively trying to pursue deployment of EV charging infrastructure, but they have often been limited by regulators in terms of the number of EV chargers they are allowed to deploy. Regulators are struggling with who is responsible for deploying charging infrastructure, who should own and operate the chargers, and the like. Both utilities and regulators need to ensure that, from the grid side of things, the growing penetration of EVs occurs in a way that enables them to be used as an asset rather than seen as a challenge for the grid and the distribution system. Beyond the charging infrastructure, utilities should also be paying attention to the fact that EV batteries that lose effectiveness for transportation could still be effective for grid purposes; utility investments and support could make EVs more affordable for consumers by taking on some of the costs related to the battery.

In terms of heavy-duty trucking, much can still be done to improve truck efficiency, including steps as simple as proper tire inflation. Electrification is making a bit of progress in medium-duty vehicles but very little in heavy-duty, as the batteries needed would be too big and take up the volume of the truck, limiting how much freight they could move. Electrifying the commercial fleet is also hard because of limitations related to infrastructure, charging times, potential impacts on goods movement, and resistance from and training needed for truck drivers. There have been pilots on biofuels with little success, and progress has been pretty disappointing thus far in getting to advanced biofuels. There have also been pilots with hybrid and full electric engines. Depending on the duty model, it is possible that a hydrogen fuel cell truck could be viable. Even where demand is there, manufacturing has been lagging. For instance, many municipal governments want to electrify their fleets, but manufacturers still seem to be far from having widely available electric garbage trucks and the like. Meanwhile, China is dominating the electric bus market, which is still quite nascent in the United States.

The eventual path forward will shape infrastructure.

Electrification is also a less viable solution in maritime and aviation, although Scandinavia is starting to electrify some light-duty coastal fleets and ferries, and there are some beginning steps toward electric small aircraft. In aviation, the International Civil Aviation Organization (ICAO) put together the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), a voluntary standard through 2027 – at which point it becomes mandatory – to start the decarbonization of aviation fuels. Five biofuels qualify now which are renewable but not low-carbon, making their relevance questionable. The aviation industry is very engaged in trying to identify and develop options, and many manufacturers and users are exploring synthetic drop-in fuels, but lots of work is still needed. Producing jet fuel from petroleum produced via EOR done with anthropogenic CO2 would count under California's Low-Carbon Fuel Standard (LCFS), but not much of that is happening yet. There is a company taking waste gas from steel smelting and turning it into jet fuel, which is interesting, though it cannot scale up and produces inadequate volumes. Another company is trying to site a DAC-to-jet-fuel facility, which would be circular, but there is still a long way to go before that becomes a viable solution. There are potentially innovative solutions in maritime too; there is work underway, for instance, to develop container ships powered by small thorium reactors, which could also be designed to produce tons of water through desalination. It is imperative to pick up the pace to get low-carbon fuel replacements that will be needed across the economy.

The eventual path forward will shape infrastructure. For instance, for airports that are being redeveloped, the infrastructure will be very different if the plan is electric aircraft or drop-in biofuels. Intermodal switching is also an important option to remember. For example, unused rail corridors – which there will be more of as coal shipments decline – can be used to move more people and freight by rail instead of on airplanes. (The corridors can also be used as high-voltage transmission corridors.)

In addition, transportation activities can have climate impacts beyond their direct greenhouse gas emissions. International rules on low-sulfur fuels for maritime shipping could lead to lower albedo from shipping exhaust, for example, leading to an increase in warming. (Similarly, when China cleans up its SOx and NOx emissions, there will be less offset of warming by aerosols.) On the other hand, transportation can also be an incubator for technologies and policies, such as California's LCFS furthering development of cleaner fuels.

HEAVY INDUSTRY

Some industrial sectors (e.g., metals, cement, glass-making) require very high heat. Just heat from heavy industry is responsible for 10% of global emissions – bigger than cars plus freight. Almost as big as the emissions from burning stuff for heat are the process emissions from heavy industry. Both of these are hard to decarbonize, but efforts to decarbonize steel, cement, and the like are essential. Such efforts can also reduce the embedded carbon footprint of industrial and transport infrastructure.

Different industrial sectors have different potential decarbonization solutions. Efficiency is one, but given that heavy industry tends to have very high fuel costs, there has already been a lot of progress made on efficiency. There may not be a lot of headroom left short of material substitution. Heavy industry also often has large on-site capabilities that could be used for a range of distributed energy technologies, as well as microgrids to boost resilience. Beyond that, tackling heat and process emissions is difficult.

There are virtually no viable, credible options currently available for decarbonization of high-temperature industrial heat, for which the industrial sector largely relies on natural gas. Realistically, it is not possible to electrify a blast furnace. Even if feasible replacement technologies were available, existing assets would have to be fully replaced, so any solutions would involve talking about tear-down and replacement costs. Hydrogen (discussed more below) is one possible solution. CCUS may also be better applied to industrial facilities than to power plants; the 45Q tax incentive, for instance, could be great for industrial plants with relatively low first-of-a-kind costs for carbon capture.

Governments can help create incentives. Procurement, for instance, can be a strong lever. Governments are huge consumers of the products produced by heavy industry (e.g., concrete, steel), so clean procurement policies can make a difference. Other policies can also help drive emission reductions in industry, but care has to be taken that policies that reward companies that reduce industrial emissions do not create incentives for them to simply relocate outside of the United States, often to countries that rely on dirtier energy sources. Carbon costs have to be factored in to protect energy-intensive global industries.

It must be remembered that the nature of industry will also be changing, with implications for the sector's emissions. Advanced manufacturing over the next decade could see nascent technologies scale, changing some of the energy parameters in industry. For instance, additive manufacturing (e.g., 3-D printing) can significantly reduce energy consumption, as there will be no need for casting anymore, and it will be 0s and 1s sent around the world instead of products shipped by planes and boats.

NATURAL GAS & HYDROGEN

Low-carbon fuels are going to be needed in the energy economy, particularly in hard-to-decarbonize sectors. A lot can be done with electricity, but fuels will also be needed. There are robust debates about whether natural gas is one of those fuels.

Near-Term Issues

In the near term, natural gas has been one of the drivers of decarbonization, particularly in terms of displacing coal in the power sector. Over the course of the last 10 years, the global natural gas market has undergone a historic transformation. The previous market was based on long-term contracts between point A and point B that were relatively expensive and indexed to the price of oil, but the situation has completely transformed. There has been a stunning turnaround in U.S. natural gas production. In 2005, it was projected that the United States would be importing large amounts of natural gas in 2019, whereas the United States is in fact now a net gas exporter – and soon to be the largest. This turnaround is important not just because of the influx of new supply but also because the nature of the supply is such that there are no destination restrictions on it. Natural gas is now destination flexible and indexed to a hub price, which has led to a global decrease in gas prices (which are converging around the world) and an increase in competition, flexibility, and integration. Flexible U.S. liquefied natural gas (LNG) supplies have gone all over the world to wherever the market prices direct them. The global LNG market in 2019 is around 300 million tons, and that volume is expected to exceed 500 million by 2025. Countries around the world can now access gas globally in a more competitive way, and there are many small players (e.g., Pakistan, Singapore) that collectively add up to a meaningful amount of demand that can now access natural gas cheaply. The coal-to-gas substitution occurring in China, Europe, and elsewhere, resulting in significant reductions in greenhouse gas emissions, would not have happened without the global LNG market.

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The near-term impact of natural gas on decarbonization is dependent on the extent of flaring and methane release that occurs. The breadth of work on lifecycle analysis across unconventional and conventional gas in the United States has found that, on average, from well to burner tip (including exploration, production, all pipeline pieces, and fugitive emissions), the carbon footprint of gas is about half that of coal, but there is a big range of findings in the literature.

Gas production in the United States is still increasing rapidly, and that is expected to continue. This is largely driven by gas that is associated with oil in the Permian Basin. Most companies drilling in the Permian are focused on oil, not on the associated gas, but the volumes of gas are enormous. There is no way it can all be consumed in the United States, so greater investment is needed in export infrastructure. Infrastructure is currently the big limitation. There are not enough pipelines to take the gas, and gas storage is full. As a result, a lot of gas is getting flared. The United States is flaring as much as 2 billion cubic feet per day of natural gas, not all of which is reported as wellhead flaring. (Flaring may be double the wellhead numbers due to flaring in other parts of the chain.) The United States is the fourth largest flarer of natural gas in the world, and if it continues on its current pace, it will become the largest. There should perhaps be penalties for flaring, increasing over time, but there should also be more policy support for pipelines. There is more pipeline capacity under construction, but midstream is building more liquids pipelines than gas pipelines. It also takes time to get landowner support along pipeline routes, and growing public opposition to pipelines makes it even harder.

Methane emissions from leaks and intentional releases – regulations on which are being affirmatively walked back – also undermine natural gas's greenhouse gas profile. Methane is a very powerful but short-term climate forcer. Fugitive emissions are more of a problem in older infrastructure than in newer. Some wonder if natural gas utilities could demand from natural gas pipelines and producers a performance standard for fugitive methane as a requirement of signing a contract.

Long-Term Issues

In the long-term, the expected boom in gas production and exports is in conflict with meeting climate targets. While U.S. growth might offset production decline rates in other parts of the world, and while gas plays a role for decades in most global deep decarbonization scenarios, the expected levels of gas production and usage are incompatible with 2°C targets, much less 1.5°C targets, at least absent massive CCUS deployment. If gas use continues and grows unabated in industry, buildings, and elsewhere, climate goals will be unachievable.

Trillions of dollars of natural gas infrastructure is already built around the world, so it is essential to figure out if natural gas is part of the low-carbon future or not. If not, it will be necessary to either strand all that infrastructure or replace the natural gas in it. Stranding the infrastructure will be very pricey and would be a huge political challenge;

the country is having a hard time leaving even a few hundred million dollars' worth of coal plants idle. Looking at a map of U.S. natural gas pipelines, it becomes clear where infrastructure would be stranded – and why resistance to an energy transition is stronger in some regions than others.

Replacing residential natural gas with electricity is technologically feasible, but it would be a lot of added – and very spiky – load, which would change capacity factors, amortization factors, and other elements. There are also the cooking aficionados who will only cook with natural gas, making decarbonization of residential natural gas use that much trickier. In addition, people like using gas. Electrifying current natural gas uses in buildings could also increase people's expenses and have disproportionate impacts on low-income populations.

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Some therefore argue that using the existing infrastructure in an optimized way would be preferable. Replacing the natural gas in that infrastructure could suggest a role for biogas (i.e., biomethane). Some natural gas utilities are exploring or pursuing initiatives to reduce greenhouse gas emissions through use of renewable natural gas (RNG) from landfills, agricultural waste, and dairy waste. RNG is methane and, once cleaned, can be injected into the pipeline system and mix interchangeably with gas. (Independent research on the impacts of biogas injection is often decades old; there have been some recent studies looking at safe injection levels, but there is a role for industry to update the analyses.) RNG cannot replace all of natural gas demand, but it can be an important niche piece. Biogas, for example, offers a more affordable option to improve the carbon footprint of industrial manufacturers who need high heat and for whom electrification is infeasible or unaffordable.

Hydrogen is another one of the key potential replacement options for industry and other natural gas users. Hydrogen, for any given volume, carries much less energy than natural gas – hydrogen has less energy density – so meeting current natural gas demand with hydrogen would necessitate much higher volumes of hydrogen. Hydrogen molecules are also hard to compress and liquefy, but there are many ways of making hydrogen piggyback on other things to become easily transportable (e.g., as methanol, as ammonia).

There are still questions about how much hydrogen can be safely blended into the natural gas system. The consensus is that up to 5% does not have any real effect on the consumer end of things or raise any safety concerns, but other parts of the world are much further ahead than that. In England, Australia, Japan, Korea, and elsewhere, they are looking at increasing percentages to 10% or 20%, and some places are looking at 100%. Some technical experts say hydrogen blending is safe up to 20%, but the effects are pipeline- and application-specific. Above that level, the hydrogen can corrode the metal, affect burner tips, and otherwise become expensive and dangerous. As percentages go higher, there will be a need to upgrade the existing infrastructure. In the near term, natural gas utilities are working with regulators on hydrogen injection standards. Looking ahead to 2030, there are things gas utilities and regulators really need to be working on and figuring out to be ready, especially regarding changes by end users (e.g., industrial consumers). Some experts see hydrogen – which burns hot and clear – as a better fit for industrial sectors, which have trained professionals, than for residential homes.

Hydrogen burns clean, but its climate benefits depend largely on how it is produced. Some expect there to be a transition from gray hydrogen (produced via steam methane reformation with no carbon capture) to blue hydrogen (produced from methane with carbon capture) to green hydrogen (produced via electrolysis from excess renewable electricity). Today, green hydrogen costs far more than blue, which in turn costs far more than gray.

Natural gas power plant designs based around oxycombustion and full carbon capture represent a promising avenue for blue hydrogen. Instead of using heat from oxycombustion to produce electricity, the heat could be used for steam for reforming hydrogen, yielding cheap, zero-carbon hydrogen. (The heat could also be used to support DAC systems.)

Green hydrogen will require significant overbuild of renewable energy, but there are already locations with so much surplus solar and wind power that it is being curtailed. In California, for instance, more and more renewables are getting curtailed, but transmission lines are not getting built to send that extra power where it is needed. Power-to-gas systems could be a key technology both for long-term energy storage and for producing hydrogen (or taking the added step of converting that hydrogen via methanation into RNG) to inject into the gas system. The technology for power-to-gas today is pricey and far short of where it needs to be, however. Lots of innovation is needed in the space, but there are almost no federal R&D programs on it.

While promising, hydrogen has a range of limitations, and there are limited amounts of biogas. Deeply decarbonizing the natural gas system and the sectors that rely on it, therefore, will also likely involve direct air capture, afforestation, and other negative emissions.

COOLING

While natural gas is often used for heating, cooling buildings presents its own climate conundrum. A warming world and growing urbanization will result in an additional billion air conditioning units installed around the world over the next decade, and that figure will keep increasing. The business-as-usual energy consumption from cooling is expected to be equivalent to adding another China to world energy demand by 2050. In addition, the refrigerants used are still mostly hydrofluorocarbons (HFCs), which have very high global warming potentials (GWPs). The refrigerants are not supposed to be emitted, but they often are, such as when units are reloaded. (This is less of a problem in the United States than elsewhere in the world.) Under a business-as-usual trajectory, just the HFC aspect adds 0.5°C of warming. At the same time, more than a billion people in the world today face serious health consequences from heat, and that figure will grow due to climate change, so there is a moral and ethical obligation to provide cooling. Studies have found that extremely hot days had limited impact on mortality in the United States because of air conditioning but had a much more notable impact in India, where there is less air conditioning. Hence the conundrum: the need to provide cooling without exploding carbon budgets. The need for cooling is a ticking time bomb on the road to decarbonization and requires more attention.

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Emissions from the energy use for air conditioning have to be slashed, and some reductions will come from aggressive decarbonization of the grid and continued efficiency improvements. With regard to the HFCs, alternative low-GWP refrigerants are increasingly available, but some in industry and governments are dragging their feet on implementing them (and on advancing the Kigali Amendment to the Montreal Protocol). While some of the units with new refrigerants do have lower efficiency, that may not be as important if the grid gets decarbonized.

There is a Global Cooling Prize competition underway to develop household-level air conditioning systems that have much lower carbon impacts, factoring in both coolants and energy usage. Low-carbon cooling represents an industrial opportunity. The United States has the potential to manufacture new refrigerants and low-impact air conditioning systems for the world. Solving the cooling challenge is in many ways more about will and regulation than about science and technology.

ROLE OF INNOVATION, DIGITIZATION, & SMART CITIES IN DECARBONIZATION

Innovating new technologies in the energy space, expanding the use of digital technologies, and deploying a range of connected technologies in cities will all play key roles in deep decarbonization.

INNOVATION

Achieving deep decarbonization by mid-century will require technological breakthroughs, which means innovation is absolutely central to the decarbonization challenge. One thing that is certain about the future is that experts have no real clue what a low-carbon system in 2050 will actually look like. It is therefore important to have a tech-agnostic system that supports innovation.

Innovation resources, however, are not evenly distributed. There is a strong correlation, for instance, between where broadband is lacking in the United States and where clean energy innovation is lacking. There are 7 states in which more than 20% of the population lacks broadband internet, and 22 states with 11%-20%. Broadband access and innovation ecosystems are essential for a transformed energy economy, particularly one that relies on decentralized, advanced, "smart" resources and technologies.

Within an innovation ecosystem, rigorous analysis is an essential first step in evaluating technologies. Computational analysis, for example, can help narrow down where the experimental needs are. Integrated risk assessments can provide a sense of what it will take to implement and integrate technologies. One of the key elements in analyses involves understanding what the price of technologies and systems will be, but many prices or estimates given to government are biased to the high side because no major supplier wants to quote the margin implied in their goods. Accurate pricing is generally only accessible by the private sector in competitive environments; partnerships of some kind with the private sector will be necessary.

There are numerous pinch-points in the evolution of technology from idea to shelf. The stages of innovation that need focus are not just research and development (R&D), but also demonstration and deployment (RDD&D) to move technologies along the pathway to commercialization. The private sector generally underinvests in RDD&D because of the expense and uncertainties involved. In government-supported RDD&D, technology readiness levels (TRLs) provide some sense of categorization to evaluate technological maturity. The Advanced Research Projects Agency–Energy (ARPA-E) is nimble enough to be able to explore new ideas quickly and is terrific at driving the early stages of basic research and innovation, including with "open calls" that are not limited by subject matter, but the problems really come in at the later TRLs. Initially, ARPA-E was meant to target two areas for gaps – early-stage and some later-stage – but the latter has never really been activated. Most ARPA-E awards are for three years and go to the private sector, universities, and others. ARPA-E awards have led to about 75 startup companies, most of which have already failed, as is typical in innovation. Some of the startups, though, have graduated to getting private capital or have been taken over after the three years by other Department of Energy (DOE) energy programs that make bigger investments to go to the demonstration phase.

DOE should continue to advance demonstration project programs. The national labs, however, punch below their weight, compared to universities, in terms of transitioning technologies to commercial development. In universities, a major part of the workforce is very mobile, in the form of grad students and post-docs, so if something good is devised in a lab, they can easily move into a spinoff company, with the faculty member serving as a science advisor. It is the opposite in the labs, where there is a very stationary workforce without a flow of students. That is a somewhat simplified, exaggerated characterization, but it speaks to some of the differences in commercialization. Still, DOE support for innovation is vital. For example, grant money from DOE helps utilities get R&D and innovation initiatives through their regulatory agencies, which otherwise tend not to allow for much R&D work. DOE's science and energy R&D budget has gone up 30% over the past 5 years, which is pretty good in this budget environment, though it is far from the doubling that had been pledged under Mission Innovation. More dedicated funding streams to support innovation are needed, including support for regional innovation clusters and ecosystems.

Companies in the deployment business have to take innovators seriously, find ways to engage with them early, and be ready and able to purchase and deploy their innovations.

Other government tools to address the commercialization challenge include tax credits (both investment tax credits up front and production tax credits over time) and command-and-control mandates. Procurement is another; government procurement could mark up products for their carbon footprint, putting carbon-free technologies on a better footing.

In addition, the government could create new entities to accelerate deployment of innovations. For example, the government could establish a technology deployment leadership council that consists of tech leader CEOs. Companies in the deployment business have to take innovators seriously, find ways to engage with them early, and be ready and able to purchase and deploy their innovations. The government could convene a leadership council to expose companies to emerging technologies that have been vetted and advanced by ARPA-E or other governmental bodies.

Another entity to advance tech demonstration and deployment could be a governmental or quasi-governmental financing entity that could provide equity and has the flexibility to range across the whole low-carbon space of demonstration projects, potentially drawing on models such as the Synthetic Fuels Corporation and the proposed Clean Energy Deployment Administration. The Syn Fuels Corporation was one of the fast-start programs in the Carter Administration, formed by legislation in the late 1970s as a quasi-governmental corporation with a mission to quickly develop substitutes for imported oil. Even though the biofuels plant it supported is still operating, oil prices dropped, and it never achieved its market share goals – and so the Syn Fuels Corporation is generally regarded as a disaster and a failure. Fast-start programs are hard because technologies and market circumstances change so rapidly, but they can successfully demonstrate and advance technologies, as Syn Fuels did.

DIGITIZATION

Digital technologies can enhance capabilities and reduce transaction costs (i.e., the costs of engaging in exchange with other people or entities). At the margin, as digital technologies make it easier and cheaper to engage in activities and exchanges, things that used to be done in vertically integrated firms – or that were not done at all – can happen more economically through market processes. Such technologies make it possible to envision and deploy a new digital infrastructure that sits across utilities, cities, agriculture, transportation, and more, driving decarbonization and a range of other benefits.

Within the power sector, for instance, an optimized, decarbonized grid will require digitization. DERs and digital capabilities create the potential for more value creation through two-way power and information flows, the use of transactive systems, and small-scale, granular, local markets. Digital technologies and automation can enable devices to respond to data (e.g., prices), assuming there is a digitally enabled distribution grid layer and a market layer. It has to be made easier for utilities (both electric and natural gas) and others to invest in many of these "smart" technologies, but cybersecurity concerns also have to be addressed.

The availability of digital technologies needed for climate-related innovation and solutions will be contingent on the actions of regulators outside the realm of energy and environment. Sometimes, those regulators – who are challenged in trying to keep up with the pace of innovation – might be better off staying out of the way in order to help meet carbon goals. For example, regulators should perhaps refrain from regulating industrial applications of artificial intelligence (AI), which will fuel smart cities, smart manufacturing, energy production, automated transport, product design, and much more. Industrial applications of AI are very different from consumer-facing applications of AI, where people's privacy becomes a more relevant concern. Likewise, the Commerce Department has a rulemaking on export controls around emerging technologies – such as AI, additive manufacturing, and quantum computing – which could impede global innovation in the energy sector. This rulemaking, which is an outgrowth of U.S.-China geopolitics, proposes changing the paradigm of export controls from one based on national security to one based on economic competition – which could cover anything and everything regarding innovation.

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There are also areas where actions by regulators will be essential. For example, industry has desperately – and so far unsuccessfully – been seeking regulation from the Federal Aviation Administration and other global regulators on drones. Industry cannot scale up use of drones unless they know the rules of the sky. Likewise, spectrum is the lifeblood of all the smart digital technologies, but communications carriers have spectrum all buttoned up at the Federal Communications Commission (FCC), with the focus solely on consumer-facing 5G. The FCC has to hear more about the need for digitization in the energy sector and the industrial sector.

SMART CITIES

The modernization of digital infrastructure is one of the underpinnings of an increasing trend worldwide towards smart cities and connected communities. While smart cities began as a tech play, the concept has expanded to become a broader infrastructure modernization concept that is facilitated by technological developments. Current infrastructure – physical, digital, and social – is inadequate to deal with the explosive rate of change in global urbanization and must be modernized and integrated with all the essential services urban residents need. The incredible urbanization occurring around the world and the drive for smart cities will overtake a lot of the conversations about decarbonization.

To scale up smart cities while accelerating decarbonization, there is a need to double down on modernization of grids, telecommunications, transportation, buildings, and energy efficiency and conservation. Connected communities can involve elements such as microgrids (or microgrid clusters), distributed solar, EVs, batteries, energy efficiency, and more. There are smart city solutions around the world that can be studied and adapted.

Utilities are underpinning a lot of the progress in smart cities. Their investments, resources, technologies, reach, and ability to be leaders are helping to make smart cities happen. Utilities generally make money from smart cities the way they do for everything else – by getting a return on investments in infrastructure (e.g., microgrids) and, in some jurisdictions, in energy efficiency. Public power entities have special leverage to advance smart cities and connected communities, as they are owned by the community.

There have been some challenges for utilities, though. For example, smart cities by their nature involve the transfer of lots of data, but for utilities, that data is tied to the customer. It can be hard for utilities to share it, even with partners, since partners want to use the data differently. In addition, even where utilities have opportunities to invest in smart cities, energy storage, and more, they have sometimes been blocked from being able to do so by environmental advocates, many of whom have been going after utilities as enemies for so long that they seem unable to shift from that course.

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While utility involvement has been pivotal, utilities do not need to "own" smart cities. Cities themselves can "own" them and bring together the various relevant agencies and utilities (e.g., power, water, housing, transportation) to make them work. The concept of ownership can also be broader, bringing in an equity lens. Customers can be the future owners of the smart city economy, such as via smart grid co-ops (along the general lines of rural electric co-ops) that give people in low-income communities equity ownership and access to jobs, services, and products. Beyond decarbonization, there is a need to be deliberate about aligning policy outcomes with real community ownership and letting people build wealth.

Smart, connected communities can advance equity in other ways as well, such as by installing solar on public housing buildings, creating an EV ridesharing program for seniors, and creating energy efficiency sharing programs that let earned energy savings be used to reduce bills or contributed to local community organizations. The new technologies can also be used to support learning and vocational development programs at local high schools or colleges.

As with digitalization in general, federal government assistance with enhancing cybersecurity around smart city development is critical. The more that smart cities rely on flexibility and connectivity, the more cyber exposure and vulnerability they face.

ROLE OF FINANCE & TRADE IN DECARBONIZATION

Achieving decarbonization of the economy will require accelerating the flows of capital into low-carbon solutions, as well as the deployment of low-carbon technologies around the world. Finance, markets, and trade have no inherent moral compass, though, which means their direction and ambition need external sideboards and direction – from policy, consumers, philanthropy, communities, or shareholders – to be aligned with achieving decarbonization.

FINANCE & INVESTORS

The low-carbon transition will require a lot of investment. Trillions of dollars in investor capital will happily support the transition if it represents the low-cost way of delivering energy, which may require a cost on carbon. Putting climate risk, carbon value, and emission reduction benefits into the economics of deals, the valuation of enterprises, and the return profiles of investments could more efficiently and appropriately allocate capital toward climate solutions.

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Even absent a meaningful carbon price, governmental finance mechanisms can encourage technology adoption, such as by de-risking investments. State green banks are one such de-risking mechanism that can help move capital into clean tech adoption. Hundreds of billions of dollars have also been invested in green bonds since the Green Bonds Principles were adopted. These types of efforts have recast the role of government as trying to de-risk the flow of private capital and to guide it into green solutions.

There are a lot of financial resources in both the public and private sectors that can be brought to bear. For example, on the public sector side, there are numerous federal, state, and local programs directing dollars into solutions. DOE's loan office still has tens of billions of dollars in loan authority that could be used. Federal funding could also be used as leverage to backstop state green banks. Billions of dollars in rents and royalties from leasing of federal energy resources could theoretically be used for clean energy as well. On the private sector side, the oil and gas industry has been very good at mobilizing investment for major capital projects, and the industry is starting to invest a little bit more in various clean energy technologies.

Likewise, the access that regulated utilities have to very low-cost capital is a potential tool for mobilizing finance for the transition. The lifeblood of zero-marginal-cost electricity is the cost of money, and one of the social benefits of a utility is its gigantic balance sheet and low cost of capital. The low PPA prices for renewables (and storage) that have been seen around the country are due to utilities with the balance sheets to cover them; they are a key low-cost way to finance such deployment. Regulated utilities in California, for instance, have been among the best tools of public policy the state has for setting goals and raising private capital to achieve them. Investors invest in regulated monopolies because the returns are predictable, given the allowed rate of return on invested capital. If that model and the credit strength of utilities are undermined, the price of renewable electricity could go up. (It is worth remembering, though, that utility balance sheets are dwarfed by the balance sheets in Silicon Valley, where technological transformations are occurring.)

While the regulated utility model can be used as an accelerant to climate goals, it can also be an impediment. Utilities do PPAs for renewables, but they also do them for conventional generation, and utilities' 25-year PPAs with coal plants are an obstacle to decarbonization. In addition, investor-owned utility monopolies are looking out for their shareholders; it is impossible to ask them to focus exclusively on serving the needs of customers and society.

Indeed, most public corporations formed in the United States are C corporations and have a fiduciary responsibility to make money for shareholders. There are new structures now in place, such as B-corps, that can take in other considerations, but most companies are C-corps. Politicians and activists can criticize them for their focus on shareholder returns – and many activists, particularly young ones, may not even know what corporate fiduciary responsibility is – but that is the law. If the desire is to have utilities and other corporations work to move to a zero-carbon world, then changes in law will likely be required – whether changes in corporate charter law or just mandatory requirements in law and regulation, which businesses have to comply with. The legal and regulatory systems can be used to elevate customer and society needs and direct the priorities of utilities and other companies.

Regulatory change is not the only avenue. Shareholders can pressure companies for change as well.

Regulatory change is not the only avenue. Shareholders can pressure companies for change as well. If the agreement between a company and its shareholders changes, then the company's actions can change too. In other words, investors can help corporate notions of fiduciary responsibility evolve. In particular, there are four index companies that, combined, own part of every stock in the S&P 500. If they voted their shares and engaged with corporate leaders in favor of climate action, they would get attention and reaction. Long-term investors can also try to drive companies to think about the long-term impacts of climate change on business.

Ratings agencies are one of the key guides for investors interested in environmental, social, and governance (ESG) issues, but there is a sentiment that ESG ratings agencies need a lot of education and lack expertise. They are seen by some as just being a racket. Still, ratings agencies are focusing on ESG issues, including climate risks, out of pure risk avoidance. The agencies are worried that if businesses do not pay attention to shifting consumer demands, technological developments, and climate change impacts, they will fail and default on their bonds. Applying ESG factors in bond ratings could be a quiet move with huge impacts in terms of integrating environmental and carbon risks, affecting the cost of capital, and moving asset-heavy, debt-reliant markets.

TRADE

While finance must flow into climate solutions, the significance of any technology in deep decarbonization will be proportional to the extent it is traded from where it is developed to where it has to be used. The low- and zero-carbon technologies that exist and that are being developed have to get to the places where they are needed. Leadership in energy will come less from domestic abundance and more from the ability to produce clean energy cheaply and get it into global commerce in many directions. Global deployment of technologies requires trade.

Global trade in solar, for instance, was key to some of the cost breakthroughs that have occurred. Trade, however, does not just involve tangible, finished products. Critical materials, which are concentrated in some countries more than others, will also have to be traded globally, and there are some U.S. concerns about not developing enough domestic supplies. In addition, in a more electrified world, there will need to be more cross-border electricity trade, which has consequences for energy security and geopolitics that have to be deeply considered.

China dominates the trade flows of many clean energy technologies in terms of assembled products, particularly solar modules, but the trade flows in solar components are a little different. For example, the United States has a positive export profile on polysilicon but does a lousy job of processing it, so solar cell production has been almost totally offshored.

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Lithium-ion battery cells have a more dispersed trade network, and there is a real opportunity to rethink some critical components of the battery supply chain. Cobalt, for instance, is a critical material that has an at-risk supply chain globally, but the United States can supply about two-thirds of the cobalt it is expected to need by 2040 by expanding recycling of spent lithium-ion batteries from U.S. vehicles. The United States also has tons of other crucial materials; they just are not developed.

In small hydro, there is a fair amount of strength in the U.S. manufacturing base. It is worth thinking about trying to standardize turbines and turbine sizes – in other words, to take a good design, scale it, and then modularize its installation. The situation with geothermal is similar. Geothermal has the challenge of being very site-specific, with systems often having a bespoke design for well structure, extraction, the power plant, and more. That makes geothermal more expensive. If geothermal turbine design could be standardized, manufacturing volume could scale with decreased costs.

Some countries are moving faster than the United States on big industrial policies that benefit trade, jobs, and climate opportunities. In China, for instance, the city of Shanghai is funding EV centers to spur EV development and adoption; they are making good cars, the prices are coming down, and they will go global. China is also pursuing its Belt and Road Initiative to create trade export routes. The lock-in of emissions associated with the fossil fuel infrastructure that China is funding and building through the Initiative (e.g., coal plant development in Southeast Asia and elsewhere) is detrimental to global emissions reduction goals and hard to undo. Climate also is not the only basis for geopolitical concerns about the Initiative, but there is not much the United States can do about it. The U.S. pushback has mostly been to reconstitute the Export-Import Bank and to revise the Overseas Private Investment Corporation into a new International Development Finance Corporation. The sense of some experts is that the United States is not making the choices needed to compete.

In any decarbonization scenario, to protect energy-intensive industries and avoid outsourcing emissions, policy tools such as border adjustments will be needed. The actual mechanisms are very complicated, though, leading some to wonder if they would really be administrable. Even though excise taxes and similar measures have been implemented at every country's border for decades (or longer), the climate context seems more complicated. For example, the carbon content of a good (e.g., steel) coming into the United States is really hard to assess, as it can vary by country (and even within different parts of countries, and among different plants within those parts). The complexities mean such a system would be very susceptible to protectionist pressures. This is not to say it cannot be done, but just that it will be hard and necessarily imperfect.

DECARBONIZATION POLICIES & POLITICS

In many ways, policies are driving the low-carbon transition. In policy-focused circles, people often leave out the role of technology, innovation, markets, and finance – but likewise, in those circles, people often leave out policy. Markets are indispensable and will be the most powerful sources of change and transformation, but markets do not make strategy for society and cannot account for externalities – by definition – without society weighing in via policy on which ones should be accounted for. Policy matters.

POLICY DESIGN CONSIDERATIONS

In designing climate, energy, and environmental policies, it is important to learn lessons from the past. For example, it has typically been lawyers and economists that have drafted a lot of the policies, under the assumption that people follow rules, but policy structures need to be more carefully targeted and designed to craft the incentives required to actually change behavior. Lessons also have to be learned about where the money will come from to accomplish the desired goals, as government will never have money at the scale and speed necessary. In addition, problems in the past have been pursued in silos – air, water, waste, etc. – but they are linked, as are energy issues, equity issues, and issues around the speed of regulation. Policies going forward should take a more integrated perspective. Furthermore, the 20th century model of regulation was based on the belief that regulators had too little information, but modern policies have not been remade to factor in the wealth of information that now exists.

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There has also been too little attention paid to the need for innovation as an element of the policy strategy, including innovations in tech, policy frameworks, finance, partnerships, and public engagement. For instance, many people will trumpet the shale revolution as a result of the free market, but there were many governmental roles, including DOE support for reservoir characterization, public-private partnerships with a dedicated funding stream (a charge on interstate gas transmission), a time-limited tax incentive passed by Congress, and more. Likewise, a DOE public-private partnership in the late 1990s funded the first several hundred grid-connected solar photovoltaic systems in the country. Subsidies and government support can play a big role. One of the biggest hurdles to innovation is reaching Serial No. 1 of a technology, de-risked enough for large-scale purchases. Tech-agnostic tax credits to promote Serial No. 1 technologies that reduce or eliminate carbon would also be valuable.

There is substantial opportunity to reimagine how information can be used as a tool of policy as well. Government, for instance, can help shape the flow of information into the marketplace around corporate sustainability and climate performance, such as by standardizing a consistent ESG investment framework that has data integrity and some kind of enforcement. The public can also be a powerful force with information tools; with smartphones and social media, everyone can be a watchdog and share pictures of bad corporate behavior.

All these elements of a deep decarbonization policy framework – as well as ensuring an equitable transition to a clean energy future, investing in climate-resilient infrastructure, designing and deploying large-scale carbon management systems, and supporting sustainable and secure clean energy supply chains – need quick, deep analytical dives to ensure the policies are designed correctly. The basic principles of such a framework – flexibility, innovation, equitability, comprehensiveness, and a focus on building effective coalitions – are applicable at any level of government, whether national, regional, state, or local.

CARBON PRICING

It will be impossible to accurately pick and choose zero-carbon technologies, from a macro perspective. That is why a financial incentive could be helpful in deploying the right technologies at the right place and time. One such incentive for decarbonization is a carbon price. In addition, it has been a principle of law for hundreds of years that people who cause harm should either stop causing the harm or pay for the harm caused – and a carbon price would force such payments.

Many argue that a carbon price should begin at a low level – so people are not overly burdened and so more people can get on board politically – and should then rise steadily and predictably to influence long-term decision-making. The low prices often proposed in carbon pricing bills, though, might be tech-shifting for the electricity sector – where even small differences in the price per kilowatt-hour can affect which resources get deployed to meet demand – but the price impacts will be far too low to be tech-shifting in other sectors. In addition, carbon pricing bills in the current Congress start small and grow over time, but even with that growth, their highest carbon prices are still half of what would be needed to achieve a 2°C trajectory with carbon pricing alone. Pricing is important and would send necessary signals, but it has to be part of a larger suite of decarbonization policies.

Carbon prices are not just price signals but also revenue raisers.

It should be noted that the goal is not necessarily to have a high carbon price. If the carbon policy is designed well, and there is an upper bound on costs, then it should be a victory if the policy goal is achieved at a low carbon price. Cheap compliance is good as long as the target is stringent enough and is achieved.

In addition, carbon prices are not just price signals but also revenue raisers. The money raised by carbon pricing can be used to help thread some political needles, engage some constituencies, and address some policy needs – whether through dividends, adjusting other taxes, increasing green spending, or other avenues.

SIMPLIFICATION

Some see the climate policy challenge not as having a lack of carbon policy but rather as having too many policies, creating a veritable thicket of federal, state, and local mandates and incentives that is neither strong nor simple enough. The mass of well-intentioned incremental policy mandates and incentives represents the equivalent of a massive tax on innovation for the low-carbon future, showing up in the cost of raising money to build new stuff. For instance, policies at different levels of government are often poorly coordinated, causing friction and confusing bottlenecks that affect the ability of companies to actually implement low-carbon solutions.

All of the subsidies, tax credits, and other incentives adopted over time were adopted for a reason, but the landscape needs to be reevaluated. It is time to let the thicket of policies go and to simplify instead to match the speed and scale of markets. Policy could, for example, set a clear mandate for the power sector, such as in the form of a tech-neutral clean energy standard with a cost cap, after which the market will begin investing towards it. Policy could simplify transportation mandates, streamline infrastructure permitting, and convert all energy subsidies (investments in today's tech) into R&D support (investments in tomorrow's tech). That combination could be an investible policy mix and would be the opposite of the piecemeal approach being pursued in many places. This sector-by-sector approach will also be easier to achieve than an economy-wide policy; from a global perspective, it might yield bigger reductions as well, since sectoral solutions may be more easily transferrable across borders.

POLICY TRENDS

Conversations often focus on U.S. federal action, but subnational action matters. States, provinces, and cities around the world are taking action distinct from what is happening at a national level, as they can speak in a more immediate way to the concerns of their resident citizens and corporations.

In the United States, as of August 2019, there were 8 states with 100% clean energy goals in place, with others exploring such goals. As a consequence of such commitments, as well as other governments' commitments, 1 in 4 people in the United States live in a community, city, or state that has committed to 100% clean energy. Just a few months earlier, it was 1 in 5. Momentum is building on this quickly. The shift from focusing only on renewable electricity to allowing for all clean energy allows for more ambition, a wider political agenda, and discussion of the right topic for deep decarbonization.

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Not all of the goals are set at a broad, overarching level. For example, New York recently adopted very aggressive goals on emission reductions, carbon-free electricity, renewables, offshore wind, storage, distributed solar, and energy efficiency – all codified. The next couple of years will see lots of working groups and task forces in the state trying to figure out how to actually achieve them. California, meanwhile, has passed one of the most efficacious carbon pricing policies and suites of complementary policies implemented anywhere at scale, aiming not only to act for itself but also to provide leadership for other subnational governments to follow. When jurisdictions such as these etch a policy goal in stone, they set a target for the private sector to reach for. Business leaders may complain about policies, but they also value the certainty and clarity they can provide.

At the federal level, there has been a different but also promising trend: the shift in political rhetoric in Congress regarding climate change. Denialism is much more a thing of the past (though it is not yet gone). Sen. John Barrasso helped break the ice for the Republican caucus even before the 2018 elections, acknowledging climate change as a real problem and promoting innovation, nuclear power, and CCUS as solutions. The Republican leadership of the Energy & Commerce Committee penned an op-ed promoting Republican solutions to climate change. Republicans chose Rep. Garret Graves – who is seen as a practical politician that cares about coastal resilience – to lead their party on the House Select Committee on the Climate Crisis. The change in Republican tone helps to open the door for discussions with a broader set of stakeholders and policymakers.

The shift in tone and emphasis is not limited to Congressional Republicans. Over the past 30 years, the discussion and debate on the global climate agenda has fundamentally transformed to the point where it is now a central issue. In another 30 years – by 2050 – perhaps it could change as much again.

THREADING THE POLICY NEEDLE

The climate policy challenge is framed by three needs. Climate policy has to be legislatively realistic, politically sustainable, and effective at actually solving the global emissions problem. The challenge is to find policies that fit in that currently narrow area of overlap – and to find ways to expand that area.

Legislatively realistic policy can be hard to achieve. Still, in 2018, policies were enacted by a Republican-controlled Congress and signed by President Trump that deployed tens of billions of dollars in new zero-carbon incentives, R&D spending, and authorizations, including focuses on advanced nuclear and CCUS. In voting for 45Q, Congress indicated that a $50/ton carbon price was acceptable. These measures show that, if cast in the right way, climate solutions may be legislatively realistic. Though all of these measures are limited, rather piecemeal, and generally focused on the power sector, they still move the ball forward.

Politically sustainable policy is harder. It will require public support, influencer support, some alignment on what the right policy is, energy markets creating the right conditions, and policymaker will. The impacts of climate change that are being felt across the country and around the world are making the public aware of what it really means to be affected right now by climate change, which may speed up political accountability. While global public support for climate action is rising, so is backlash (e.g., the yellow vest protests in France), and public ballot measures on climate have failed in very progressive states such as Washington. The yellow vests were protesting climate action that was seen as too swift and too expensive, at the same time that students are protesting that climate action is too slow. Policymakers are caught between the workers of today and the workers of the future. With regard to influencers, there are interesting discussions occurring, but there still remains a heavily entrenched anti-climate-policy coalition within parts of the conservative movement, as well as in the petroleum refining industry. The potential for finding policy alignment has nevertheless increased as climate advocates increasingly move past the 100% renewables vision to an embrace (or at least acceptance) of all zero-carbon sources, but there are still strong forces pushing for an end to all fossil fuels. In terms of markets, prices for renewables, shale gas, batteries, and EVs are radically lower than before, but many energy-related companies are still in a defensive posture when it comes to new policies.

Climate policy has to be legislatively realistic, politically sustainable, and effective at actually solving the global emissions problem.

In terms of policymaker will, there has been growing attention to climate due to the Green New Deal, but there is also still heavy scar tissue from the 2009 Waxman-Markey cap-and-trade bill fight. Policies will have to be designed with vote counting in mind. Discussions and education have to happen now, so that opportunities to move forward on policy can be created and seized. Policymaker will could be greater at the start of a first presidential term, at the end of a second presidential term, or when legislation or other measures need reauthorization.

With regard to policies to actually solve the global emissions problem, there has been little progress. The share of global primary energy supply provided by zero-carbon sources has been stable at about 23% for more than a decade. Clean energy development is just keeping pace with growing global economic development and energy demand; clearly, that is better than failing to keep pace, but clean energy is not making progress beyond that. U.S. decarbonization is important and needed, but American policymakers need to look at policy design with a global lens. Unless affordable tools to allow developing economies to develop in a very different way start to increase globally, the problem will not be solved.

Similar to 2018, there are some tech-specific innovation pushes on nuclear, CCUS, storage, and advanced renewables that satisfy all three needs and are moving through Congress in a bipartisan way, as well as significant new (and permanent) tech-neutral tax incentives. There are also multiple bills in Congress on direct air capture, as well as a bicameral, bipartisan bill to put some money and structure into innovation on emission reductions in heavy industry. Federal policy that is narrowly framed and executed, however, will be inadequate given the scale of transformation that has to be achieved.

STAKEHOLDERS & COALITIONS

Outside pressures can change the politics of the achievable. Jobs and equity are vital drivers of such pressures, as seen in the yellow vests in France, the youth striking movement in Europe, and conversations and protests taking place around the world linked by the common thread of people complaining that political leaders have not taken on the solutions that exist. What these protests have also shown is that the types of stakeholders involved in climate policy discussions have expanded and diversified.

Influential constituencies include environmental groups, labor unions, suburban women, and communities of color. It is essential to bring all those folks together and convince them that climate policies will make their lives better. While climate and social justice advocates may disagree on details about how and how quickly to advance a policy agenda, it is important to recognize the commonality in vision and goals.

There are many new players in the energy space as well, including ones involved with building energy management, data analytics, cybersecurity, smart cities, and drones. These are not the typical energy players, but they all have to be at the table. This can be challenging, as energy folks and digital folks do not talk the same language and often do not work together.

Climate policies have to both be up to the scale of the problem and address the concerns of core stakeholders, though it will be impossible to please everyone. A policy that is milquetoast and caters to the lowest common denominator to please everyone would not be up to the task. To craft a policy and keep conversations going so action is possible when a political window opens, coalition-building will be vital.

The goal on climate should similarly be to create a widespread network of affiliations that can deliver aligned votes in favor of federal legislation to reduce greenhouse gas emissions.

Some would argue that political economy and the need for coalitions suggest a need to work with the fossil fuel industry. Given their committee positions, Senator Barrasso of Wyoming and Senators Capito and Manchin of West Virginia will be deeply involved in any big climate policy that moves through the Senate any time soon, which means there is no world in which such a policy gets through without some support from the fossil energy community. A way must be found to have a big federal solution that allows coal, gas, and oil to continue to participate actively in that future; failure to recognize the incumbent energy industries' influence and to include them in the coalition could slow decarbonization by decades. There may be some openings for common ground, as industry CEOs have signed onto statements out of the Vatican calling for carbon pricing and corporate transparency. On the other hand, industry lobbying has also consistently killed climate bills at the federal and state levels, and there is a general lack of trust between climate advocates and the industry.

The fossil fuel industry is not the only one that could be at the coalition table. Other industries with ties to local and state employment can also be influential with senators. In addition to the big companies, there is a need to figure out how to create dialogue with small and medium-sized businesses, which tend to be the ones who go to their chambers of commerce and complain to their senators. There are also numerous organizations, associations, and other affiliations to try to bring into the coalition to try to change the political dynamics. It is important to think about the coalition needed to move Republican senators toward the middle. It also must be recognized that the Democrats are divided in their beliefs as well; it will not be a walk in the park to get them to legislation either. One reason 45Q passed was that there was a coalition behind it with companies, labor, and environmental groups. The goal on climate should similarly be to create a widespread network of affiliations that can deliver aligned votes in favor of federal legislation to reduce greenhouse gas emissions.

Different types of coalitions can achieve different objectives, though. For example, the coalition needed for one giant climate plan is likely different from the coalitions needed to move discrete chunks of policy action. Bills focused on agriculture, surface transportation, workforce, and more could all move with different coalitions. The coalition for a clean energy standard is probably different from one for a new fuel economy standard. Coalitions to pick things off one subject at a time are also probably easier.

Similarly, if one is building a coalition for legislative action in the U.S. Senate, then engaging (particularly as opposed to demonizing) industry may well make sense. If the aim, however, is to change the landscape of what is possible – in other words, coalitions of activism, such as Extinction Rebellion – then the members of that coalition may be quite different, and the language of crisis and demonization can help change the level of urgency.

SOCIAL EQUITY & WORKFORCE ISSUES

The low-carbon transformation is underway, but the question is whether society has the capacity to manage it in a way that supports common societal aspirations. The Green New Deal and movements led by youth and by people of color have changed the conversation around climate change by incorporating an indelible social justice element. There are also vital workforce equity issues that must be addressed.

Solutions to these challenges will require expertise beyond energy and environmental issues. There is not, however, a good taxonomy or sense of effectiveness of different approaches around a fair, just, and sustainable transition. Unlike health care or carbon pricing, which have fairly well understood options, evidence, and tradeoffs, there is not yet a clear set of ways of thinking about a just transition.

SOCIAL EQUITY

The need for diversity and inclusion has to be part of the discussion of deep decarbonization. It is important to ensure that the new low-carbon economy does not build in the same inequities that currently exist for labor, communities of color, and others. Solutions should aim for a fair and just system with equal access to opportunity, and policies must be crafted – and communicated – with that in mind. A transition is needed from an era in which it was taken for granted that risks could be socialized and gains privatized to a tech-enabled future where consideration must be given to the need to privatize risks and socialize gains.

That high energy costs are socially regressive, which means policies that raise energy costs are regressive

As a starting point, it must be remembered that high energy costs are socially regressive, which means policies that raise energy costs are regressive, unless carbon price revenues are used for dividends that can make the policy net progressive. Energy affordability is very important, as are energy efficiency and conservation to reduce the amount of energy used. Some see clean energy options as being more expensive for customers, while others see renewables (even with storage) as being some of the cheapest options out there. Transportation costs are also important to consider as decarbonization measures are pursued in that sector.

The equity issue is not just about energy costs, though. The broader distributive equity impacts of climate change and of decarbonization are layered on top of existing inequitable systems. Energy prices are one small slice of the equity equation. For instance, the yellow vest protests in France were mostly about broader inequity, with the fuel tax being the last straw. The first straw was an income tax cut for the richest people, and the second was a labor law change. Job insecurity and income inequality were the broader context of protests about the carbon tax on fuel.

In the United States, inequality has been growing for decades. For instance, marginal tax rates on the wealthy have plummeted over the years. Inequality in U.S. society is not something new. Some of the inequality likely ties to the globalization of labor markets, which undermined labor standards in the United States and elsewhere. The private-sector unionization rate in the United States is under 6%, and the lack of unionization has taken away the means by which working people can express their economic power, which in turn has exacerbated income inequality. The energy sector alone cannot solve this issue, but it has two to three times the unionization rates of the rest of the economy, so failure to pay attention to labor issues in the energy sector could contribute to even more inequality.

Another intersection of energy, decarbonization, and equity involves ensuring that the benefits of the low-carbon transition are widely shared. At the moment, the incentives and tax credits almost all go to the top tenth of 1%, and much of the deployment of technologies such as rooftop solar and electric vehicles is going to a similar demographic. There is a risk that those who can capitalize on storage, generation, and control technologies and can afford to self-generate will go off-grid, leaving utilities to figure out how to spread grid maintenance costs across a smaller pool. Some, however, view the notion that rooftop solar is just for white suburbia as outdated. Communities of color have been very interested in rooftop solar, and low-income communities see it as an important aspect of addressing environmental justice concerns and creating resilience in neighborhoods. In rural areas, there is likewise great potential to locate a lot of solar on land outside the circles formed by center-pivot irrigation. On the other hand, absent policy and investment, some think it unlikely that clean DERs will metastasize in low-income communities that lack access to capital.

Solutions are needed to ensure that everyone, including low-income populations, can access clean energy products.

One of the roles of government is to address market failures, including the failure to adequately include low- and middle-income Americans in the low-carbon transition. Solutions are needed to ensure that everyone, including low-income populations, can access clean energy products. Financiers of clean energy often will not serve low- and moderate-income populations because they view them as too risky, but the perceived risk may be greater than the real risk. More data is needed, but there is skepticism that FICO scores are the best way to measure risk and that churn and default rates are as high as some financiers estimate. There are lots of ways policy can more appropriately price risk in the financial system, including through green banks. Some utilities have also advanced low-income solar programs that involve no FICO scores, no upfront investment, and no subsidies across revenue.

Social equity challenges require place-based solutions, which some experts feel can only be provided by policy. (Free market forces, left to their own devices, do not correct inequities.) In various places around the country, there are programs already in place that are working well to help people who would otherwise be left behind or disadvantaged. An explicit part of California's carbon pricing policy, for example, was an equity focus, directing revenues into a mechanism that screens where the money should be reinvested. In New England and California, some companies are seizing opportunities to aggregate customer-sited resources – often in communities disproportionately impacted by pollution from peaker plants – to benefit their electricity systems and to incentivize low- and moderate-income participation in solar and battery storage. There is a need to highlight and share best practices, and successful programs should be disseminated more broadly. In addition, there is a need for guidance to help organizations figure out how to access the various pots of money available to pursue social equity and workforce solutions.

WORKFORCE

Decarbonization is having and will have a massive impact on the workforce. Workforce solutions should seek to target the whole range of communities that need assistance.

It is difficult to promote workforce solutions during this transition without first understanding where things stand in the U.S. energy workforce. In total, about 5.7 million Americans work in the energy sector (not including the roughly 1 million that work in gas stations), or about 4.5% of the private workforce. Representing such a small portion of the workforce can make it hard for energy to influence broader-scale issues in U.S. employment. Of that 5.7 million, about 20% are in fuels, 15% in electric power generation, 23% in transmission, distribution, and storage, and 41%

in energy efficiency. These jobs are divided into different geographies; there is a lot of variation among states. There is also a lot of differentiation within industrial sectors. Natural gas, for example, has jobs in everything from mining and extraction to utilities. Among energy efficiency jobs, utility jobs tend to be the best-paying but account for only about 11% of the jobs, whereas the most jobs by far are in construction, at over 33%, which tend to be the lowest-paying. Economic development strategies correlated to energy issues have to understand this variation.

While definitions vary, there appear to be more than 4 million U.S. energy jobs – including in motor vehicles – making direct contributions to lowering greenhouse gas emissions. For workers in some states, though, decarbonization (especially beyond electricity) is seen as a job killer. There are hundreds of thousands of jobs in fossil fuel sectors, and average salaries are pretty good. There have been energy jobs reports for years touting wind and solar jobs as the fastest growing, but working-class Americans are not convinced of the job benefits of a clean energy transition. Until they are convinced, change in those states will be difficult.

About 5.7 million Americans work in the energy sector.

Transitioning economies and retooling workforces are very complex and locally driven undertakings, and there are many hurdles to workforce transitions driven by decarbonization. For example, local leaders rely on local carbon-intensive industries, with things like coal severance taxes providing funds for museums, libraries, and economic development grants – so the willingness and capacity to retool the workforce in such places is not high. Jobs with new technologies also are not always a 1:1 replacement for the jobs that are lost. For example, far fewer people are needed for additive manufacturing machines than for a factory floor. (The desires for jobs and emission reductions can be in conflict; jobs are obviously important, but so is meeting carbon goals at low cost.) Moreover, theoretical jobs in the future are not equal to real jobs now, especially in the United States, where a job is the access point for having health insurance.

In many "low-innovation" states, the crisis that dominates everything else right now is the opioids crisis, which is driven by heavy-labor industry workers dealing with pain issues. As those industries decline, the problems and hopelessness are exacerbated. State and local leaders can draw a direct line from wind turbines replacing power plants to kids becoming drug-addicted. It feels to them like the house is on fire, and the clean energy industry keeps offering them buckets of gasoline in the form of things that will not bring new jobs. The climate policy conversation needs to try to offer solutions that connect to the crises these local leaders are seeing.

If climate policy advocates do not grapple with what workers who will lose jobs will be doing instead, then those workers will block passage of climate policy. Most fossil fuel workers probably are not going to be trained to be software engineers, but good-paying sales and customer service jobs could be a possibility. Others see the real opportunities as potentially being in blue-collar construction and professional business services in energy efficiency. It is important to try to figure out how to cycle investment to places so that workers and communities likely to lose jobs first receive policy-driven investment first. There is a need for better mapping of skills, jobs, training, and education to gain an understanding of where various types of needs exist and to ensure that no workers or communities end up stranded in the transition. Many great programs exist, including philanthropic, governmental, and non-profit, but more investment in those and other efforts is needed. Some have advocated for a new U.S. Department of Rural Development, as the Agriculture Department is a century-old view of what rural America is about. One way or another, leaders at the local level need locally actionable data, information, and tools to help them figure out how to restructure local and state economies.

These local leaders have not been helpless. Policymakers in coal regions have seen this transition coming for a long time, but they have sided more with coal owners than coal miners. The transition has been a slow-moving car crash that has been coming for decades, but many of these regions have yet to move or maneuver and are now being reactive.

That said, programs are lacking to help affected communities and workers, even when there are long lead times, such as when it is known years ahead of time that a plant is closing. Many workforce development policies cannot go into effect until after a worker gets a pink slip, even if the layoffs were known years ahead of time. Policy change is needed to unlock federal workforce funds earlier in such situations. An analogous situation that the federal government deals with regularly and successfully is when there are military base closures in communities. There are some great examples there of how to handle transitions – with federal funds supporting community redevelopment and with locals having a lot of say upfront – that could be studied and perhaps replicated in a plant-closing context (or other contexts tied to disruption caused by the low-carbon transition). When it is not a federal facility that is closing, it is less clear who would pick up that responsibility, but it is an interesting analogy that needs to be pursued more. There is a substantial literature on base closures, and the energy industry has not done a good job of learning from the knowledge in those studies.

> **There is a need for better mapping of skills, jobs, training, and education to gain an understanding of where various types of needs exist and to ensure that no workers or communities end up stranded in the transition.**

There are other aspects of workforce equity implicated by the low-carbon transition as well. For instance, many of the jobs that will be lost are union jobs. As noted, the energy sector has unionization rates higher than the rest of the private sector, leading to higher wages. When new technologies and business models are proposed, it is important to understand if they will contribute to greater equity or undermine what has been accomplished over generations.

Similarly, the nuclear industry is the most diverse part of the energy sector, with high levels of racial diversity and the highest rate of women in the workforce. As the nuclear industry gets dismantled, those gains are lost. The automobile industry likewise made huge contributions to bringing African Americans into the middle class, but the percentage of African Americans in the auto workforce has been declining for decades, and the loss has been accelerated by the global reorganization of that industry. Changing the structure of the energy industry and related sectors should be done consciously, with thought to how it impacts equity.

Construction-related trades are among the most important when thinking about creating equity opportunities and long-term careers. It is important to think of skills as having multiple applications. For example, solar rooftop installers have a fairly unstable occupation, and it is mostly small-time contractors doing small jobs for small periods of time. Skills can translate, however, to doing electrical work in multiple situations. There is a difference between a 12-week solar installer training program and a 4-year apprenticeship program in the electrical trades. Jobs like solar installation could potentially be used as a stepping-stone into real apprenticeship opportunities, and partnerships between unions, utilities, and governments could be effective at driving those.

Indeed, the utility industry has great potential for expanding jobs and changing the nature of the workforce for the low-carbon economy. Utilities (and other new competitive entrants) are in every community, touch a lot of people, and are a gateway to the new tech economy. The transition creates opportunities for utilities to focus on subcontractor and supplier diversity – and on having those companies hire people from local communities. Relationships are one of the most important things that businesses owned by people of color lack with utilities, so where there are new business lines and no real incumbents, there is an opportunity to reach out. Utilities also have such diversified functions that some of their workforce needs can be met by workers transitioning out of high-carbon assets, and some utilities that are closing coal plants have instituted hiring freezes until they can figure out which workers they can retrain.

Some utilities face a challenge in convincing their employees – who have seen lots of modest change over the years – that big changes are coming fast. Employees are apprehensive about being asked to learn new skillsets and technologies, particularly unionized, single-craft workers who have focused on advancing up the line of progression during their careers and are worried about what happens to their seniority. These are solvable issues, but there is resistance to change among the workforce.

ADAPTATION & RESILIENCE

Climate change is a planetary-scale challenge, but it will lead to local impacts and effects on communities. Already, fires, floods, and other disasters of catastrophic proportions are on the rise. From 2016-18, across the United States, an average of 15 major billion-dollar natural disasters occurred per year. That is about 2.5 times greater than the longer-term historical average. There will be a need for a massive U.S. adaptation policy.

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STORMS & THE GRID

As climate change helps churn up more powerful storms, power grids will be at risk. One recent, illustrative example occurred in Puerto Rico, which was hit by Hurricanes Irma and Maria back to back in September 2017, causing the longest power outage in U.S. history. Transmission and distribution infrastructure, which was already aging and poorly maintained, was destroyed or heavily damaged. There have been many challenges with restoration, not the least of which was competition with restoration efforts tied to other disasters, such as Hurricane Harvey in Texas and the California wildfires.

After disasters, it is critical to give thought to how to rebuild to reduce future risks and improve resilience. The Federal Emergency Management Agency (FEMA) has tended to fund things to be rebuilt as they fell, as required by the Stafford Act, which missed opportunities to move forward on sustainability, climate, and resilience – but the law was recently changed.

All utilities are thinking about resilience and about how to design systems to avoid problems. Part of this involves redesigning to have a more modular system and identifying the locations where there is zero tolerance for an outage. The Puerto Rican grid modernization plan, for instance, envisions a system that would include increased renewables, expanded distributed generation, more storage, undergrounding of critical infrastructure, microgrids focused on critical facilities, islandable grids (i.e., they can separate when the system is under stress), substation and distribution system automation, advanced communications technologies, and more – all to create a sustainable, reliable, self-healing grid that can serve as a model of a resilient island power system. Limited budgets, however, may hinder the ability to bring the plan to fruition. The plan has also moved to the back burner in light of the political turmoil in Puerto Rico.

Responses after Superstorm Sandy in the Northeast could also provide models for others, as many actions were taken regarding subways, gas stations, and other infrastructure. Utilities invested in hardening the system, having submersible transformers, sectionalizing flood-prone parts of the grid, deploying stronger poles, and more – and they generally rate-based the investment. The best resilience measures are not always technologies and concrete, though; they are often green infrastructure, such as mangroves.

Resilience challenges for the grid will only become more acute as other sectors electrify as a core part of a deep decarbonization strategy. It is worth thinking about how having electrified transportation and buildings could complicate resilience efforts. Regional or local transit authorities moving to electric buses, for instance, often do not have backup capabilities if the grid goes down. If transportation is electrified, then thought will need to be given to the critical infrastructure in that realm that needs backups and redundant systems.

Hardening grids, rebuilding coastlines, deploying green infrastructure, and otherwise boosting resilience are going to be very expensive endeavors. Portions of individual city budgets will be far too small. Congress, states, cities, businesses, and everyone else have to work hard to figure out how to make these resilience efforts actually happen – and quickly. There is a need for a program of resilience-building investments that combine federal, state, and local support.

After disasters, it is critical to give thought to how to rebuild to reduce future risks and improve resilience.

As part of this effort, there is a need for broader, more comprehensive climate adaptation work at public utilities commissions, including how to put risk assessments into planning paradigms. Regulators, however, do not know how to assess the value of resilience plans. Economic frameworks exist to value loss reduction, and putting together standards that define the outcomes and benefits of resilience investments will be important to get private capital markets more comfortable investing. On the other hand, while many large energy buyers generally support increasing the resilience of physical infrastructure, they often see "grid modernization" as a ruse by utilities to rate base infrastructure investments in a world of flat energy demand. They also tend not to view investments in grid and energy resilience as being a particular priority, and it has been difficult to get many businesses to spend money on resilience. Ways need to be found to break down the education and trust problems between the sellers, buyers, and regulators of power so there can be more consensus on why investments are occurring.

WILDFIRES

Wildfires are not new to California and the West, but the severity and impacts are greater due to climate change and increasing populations in dangerous areas. Climate change is leading to longer periods that are hotter and drier, interspersed with periods of unusual wetness, which spur lots of vegetation growth that quickly dries out, increasing fire risk. At the same time, more people are moving to wildland-urban interfaces, into zones at medium or high risk for fires, so there are more people in harm's way. The fires of 2017 and 2018 were particularly catastrophic, killing dozens of people, causing tens of billions of dollars of damage, and destroying millions of acres of land. The fires also released tremendous amounts of greenhouse gases and harmed air quality. It is imperative to mitigate both the risk of ignition and the amount of human life and economic property in harm's way – because the fires can spread so far, so fast, that it is very hard to stop them once they are going.

Fewer than 10% of California's fires are caused by utility infrastructure, but when they were utility-caused, there had been insurance capacity to deal with the damage. It was not until 2015 that the state started to understand that there may not be enough commercial insurance capacity available, and the 2017 and 2018 fires were a wake-up call for utilities to invest more in risk mitigation.

All California utilities have to do wildfire mitigation plans every year, but these are action-oriented rather than strategically focused on risk reduction; understanding how actions correlate to risk reduction is still a nascent field. The plans tend to focus on vegetation management (e.g., clearing trees), system hardening, and proactive power shutoffs to power-down systems during dangerous conditions. Some utilities have also pursued valuable, effective pilots that, in addition to proactive investments in vegetation management and system hardening, have included significant investments in better fire detection equipment, cameras, artificial intelligence, and more. The wildfire plans tend to pay little or no attention to the value of DERs for resilience, and, as noted above with regard to storms, the regulatory environment is not yet set up to address that value.

Utility wildfire mitigation plans are also expensive, hard to complete, and require lots of labor. If the plans are all approved, bills for residential customers will rise, and commercial customers' bills could rise even more. This becomes an equity issue, as people living in fire-resistant areas will be subsidizing people living in fire-prone regions. The resilience expenditures also leave less money on the table for investments in renewables, storage, EV chargers, and the like; there is only so much a utility can put on customer bills. The state is in the midst of trying to figure out how to equitably socialize the cost of fires.

Wildfires are not solely a California concern, and proactive power shutoffs are not just a California approach. They are becoming almost the first line of defense for utilities in fire-prone regions in the West, despite being the antithesis of utilities' missions to keep the lights on. Other entities can help. For instance, private-sector entities – particularly communications, internet, and home/building energy management companies – have a role in trying to figure out how to get critical information to people pre-crisis, such as how to identify fires that are starting, how to alert people to a proactive power shutoff, and how to pre-cool houses of, say, the elderly in advance of a shutoff.

BIPARTISAN ATTENTION

There are fires in the West, powerful storms on the coasts, floods in the Midwest, and other disasters unfolding. A lot of U.S. oil and gas infrastructure sits in the Gulf of Mexico and on the Gulf Coast, right where many hurricanes hit. It is not clear if people connect these events to climate change, but it seems like more are starting to in recent years. The fires, storms, rains, floods, and the like have made obsolete the idea that climate change is about effects on children and grandchildren in the future; it is about now and us. In addition, there is a serious social equity component, in that poor areas that get wiped out almost never come back, while wealthy areas keep rebuilding the same homes over and over that get destroyed. The silver lining in all this may be that these things people have never experienced before have gotten the attention of Senators and Representatives of both parties in Congress. This is an opportunity to get something done.

The fires, storms, rains, floods, and the like have made obsolete the idea that climate change is about effects on children and grandchildren in the future; it is about now and us.

Congressional attention to the impacts and the need to strengthen infrastructure can be an on-ramp to bipartisan engagement on climate issues. Senators from coastal states can focus on disaster resilience, adaptation, and economic development. Republicans ought to like spending less on the front end of a disaster than far, far more to recover after one. There will be different ways to have the discussion at the federal level, but politically, it is better to give people a bridge than to back them into a corner. Resilience can be the bridge home for politicians that have been in the climate denial camp. As long as Democratic members invite Republicans back to the table, a portion of the Republican membership will come.

There are several types of policy measures that might be useful – some to target the chronic aspects of climate change impacts, which require a different ongoing sensibility, and some to handle acute responses. For example, the Department of Housing and Urban Development (HUD) is sitting on billions of dollars to do some of the resilience work needed, but it cannot decide how to adjust community development block grants to become pre-disaster mitigation grants. Congress has finally created a new category in the budget with supplemental funding for fires, separate from disaster relief. FEMA has authorities and programs to do mitigation programs, but they tend not to get funded; there is a need for more comprehensive restructuring and rethinking of how FEMA and HUD respond to disasters. It is also worth thinking about a national catastrophic insurance program for everyone in the country – a public-private partnership that spreads the risks out. The government cannot pick up the whole tab, but the insurance industry and reinsurance industry do not have the capital either.

The federal government should also strive to get attuned and updated on the new generation of flood and fire analytics – and work to foster them. Technology now exists to have more or less a real-time Earth dashboard that can focus on localities and use predictive analytics to predict, say, what area will flood in what way. Almost every flood map relied on now is wrong. Technology providers can help inform policymakers on what can be done. There are entrepreneurs working on these issues, developing technologies that could save lives in the face of these challenges.

APPENDICES: AGENDA

WEDNESDAY, AUGUST 7

Opening Session

Introduction **Greg Gershuny**, Aspen Institute Energy and Environment Program

Welcome **Ernest Moniz**, Energy Futures Initiative, Inc.
Andy Karsner, Elemental Labs

SESSION ONE: **Data and Policy Scene Setting – Current and Future Outlook**

What has happened in the US energy and climate landscape over the past few years – and what is the outlook for the coming years? What technologies and at what pace are new generation, transportation, and other technologies being deployed? Is the global picture similar?

Moderator: Ernest Moniz and **Andy Karsner**

Discussants:

Michael Webber, ENGIE
Roger Ballentine, Green Strategies, Inc.
Julia Hamm, Smart Electric Power Alliance
Matt Crozat, Nuclear Energy Institute

SESSION TWO: **Envisioning the Future – Policies to Drive the Transition**

More than ever before, there are a slew of policy proposals, both state and federal, that are being offered as solutions for energy and climate change policy. What are the up and downsides of each of these proposals? What is the most effective and achievable suite of policies that can balance the dire need for action on decarbonization with realities of policy and politics?

Moderator: Andy Karsner

Discussant:

Kevin de León, Emerson Collective
Melanie Kenderdine, Energy Futures Initiative, Inc.
Rich Powell, ClearPath Foundation
Jonathan Pershing, Hewlett Foundation

SESSION THREE: **Reimagining Electricity Markets**

Is the current wholesale and retail electricity market structure set up to accommodate large amounts of zero cost electricity? If not, how should it be structured so that the market 'makes sense'? Are policies and markets interacting in a way that benefits a low-carbon future?

Moderator: Ernest Moniz

Discussants:

Lynne Kiesling, Carnegie Mellon University
Richard Newell, Resources for the Future
William Massey, Covington & Burling LLP
Nicole Sitaraman, Sunrun

THURSDAY, AUGUST 8

SESSION FOUR: **Decarbonizing Electricity – Innovation and Efficiency**

What are the existing technologies necessary to maintain or scale-up in order to quickly transition to a zero-emissions power sector? How can net-zero emissions be sustained with projected increases in power demand? What technologies should be further advanced to aid the transition? What is the role of CCUS, nuclear energy, and other new technologies as sources of electricity in the transition? How can efficiency be better deployed?

Moderator: Andy Karsner

Discussants:

Michael Terrell, Google
Bryan Hannegan, Holy Cross Energy
Julio Friedmann, Columbia University SIPA

SESSION FIVE: **Decarbonization and Resiliency Through Electrification and Low-Carbon Fuels Integration**

Meeting carbon reduction goals will require a range of clean energy pathways across all economic sectors – electricity, transportation, industry, buildings, and agriculture. As the electricity sector decarbonizes, how can other technologies be applied to reduce emissions at the economy-wide scale and ensure resiliency and affordability? What are low-carbon options for hard-to-decarbonize processes that can't be electrified? How can low-carbon fuels be commercialized and deployed for long-haul trucks, planes, and heavy industry? What is the role of hydrogen and biogas in a 21st Century energy system?

Moderator: Ernest Moniz

Discussants:

Sara Decker, Walmart
Charles Patton, American Electric Power
Maryam Brown, SoCalGas
Bill Brown, NET Power, LLC

SESSION SIX: **The Energy Trade Enabling Global Decarbonization**

How is the global trade market affected by the new energy economy, and vice versa? Trade of technology, rare minerals and metals, and commodities each have an impact on the global supply chain. How are trade and exports enabling global decarbonization?

Moderator: Andy Karsner

Discussants:

Jason Bordoff, Columbia University SIPA
Meg Gentle, Tellurian Inc.
Doug Arent, National Renewable Energy Laboratory

SESSION SEVEN: **Fires & Floods – Evaluating Climate Risks on the Energy System**

Increasing instances and intensities of wildfires and frequent flooding have already proved detrimental to energy infrastructure in the West, along coastal regions, and in Puerto Rico. How can the climate-energy nexus be improved to show greater proactivity and resilience?

Moderator: Ernest Moniz

Discussants:

Carla Peterman, Carla Peterman Consulting
Senator Mary Landrieu, Van Ness Feldman LLP
Karin Corfee, Navigant

SUNDAY, JULY 14

SESSION EIGHT: **Adapting Workforce and Smart Infrastructure for a Clean Energy Future**

What is the workforce the US needs to support deep decarbonization? How will workers in areas like coal and others be reskilled? How will aging infrastructure be updated with the clean energy transition in mind?

Moderator: Clint Vince, Dentons US LLP

Discussants:

David Foster, Energy Futures Initiative, Inc.
Anne Pramaggiore, Exelon Utilities
Paula Gold-Williams, CPS Energy

SESSION NINE: **Policy and Finance Mechanisms for Decarbonization**

What are the financial mechanisms necessary to incentivize decarbonization? What would a price on carbon look like? What is needed from policymakers to achieve a palatable price on carbon?

Moderator: Ernest Moniz

Discussants:

Dan Esty, Yale School of Forestry & Yale Law School
Jim Connaughton, Nautilus Data Technologies
Jim Murchie, Energy Income Partners, LLC
Joseph Hezir, Energy Futures Initiative, Inc.

BREAKOUT GROUPS

SATURDAY, AUGUST 10

SESSION 10: **Action Planning**

Groups from last night's dinner will provide a two-minute overview of big ideas discussed to provide an actionable conclusion to the Forum.

PARTICIPANTS

Andy Karsner, Executive Chairman, Elemental Labs *(Co-Chair)*

Ernest Moniz, President & CEO, Energy Futures Initiative, Inc. *(Co-Chair)*

Matt Adams, Partner, Dentons US LLP

Doug Arent, Deputy Associate Lab Director, National Renewable Energy Laboratory

Donnel Baird, Founder & CEO, BlocPower

Miranda Ballentine, CEO, Renewable Energy Buyers Alliance

Roger Ballentine, President, Green Strategies, Inc.

Hannah Bascom, Head of Energy Partnerships, Google

Paul Bauman, Senior Advisor, Rodel Foundation

Robyn Beavers, Co-Founder & CEO, Blueprint Power Technologies, Inc.

Jason Bordoff, Professor & Founder, Center on Global Energy Policy, Columbia University SIPA

Samuel Brothwell, Director of Research, Energy Income Partners LLC

Bill Brown, CEO, NET Power, LLC

Maryam Brown, President, SoCalGas

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