2019 ASPEN INSTITUTE WINTER ENERGY ROUNDTABLE

DECARBONIZING THE ELECTRICITY SECTOR & BEYOND

A REPORT FROM THE 2019 ASPEN WINTER ENERGY ROUNDTABLE

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THE ASPEN INSTITUTE ENERGY & ENVIRONMENT PROGRAM

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CO-CHAIRS' FOREWORD

In our Aspen Clean Energy Innovation dialogues, we have always sought to remain grounded in science and economics while taking an optimistic and aggressive view of the change that is possible in the energy sector. And we take a broad approach to convening to ensure we have in the room the stakeholders, experts, policymakers, and market players that will have to combine forces to match a great ambition: economy-wide decarbonization on a scientifically called-for timeline while ensuring national economic competitiveness and a just transition. This is our North Star.

While we enjoy great diversity among our participants, we share an openness to challenging convention and to learning from each other. Because the challenge – and opportunity – of decarbonization requires an economy-wide approach, this year we broke our discussion into two parts: the electricity sector, and the rest of the economy.

In the electricity sector, substantial innovation and decarbonization are underway. Coal is largely being phased out by policy and economics. Natural gas has played a major role in driving coal from the market, but itself poses a longer-term emissions challenge. While one can debate the timeline, there is broad consensus that gas must innovate (decarbonize) or follow the path of coal. We addressed head-on the question of what technologies, business models, and policies are best aligned with deep and accelerated decarbonization of electricity. This year, that approach led us to take a hard look at the the pros and cons of the currently popular view that renewables, and wind and solar in particular, can alone be our workhorse in pursuit of decarbonization. There is no doubt that wind and solar proliferation has been a major success story. But with decarbonization as our North Star, we looked hard at whether some have substituted "tools" for outcomes; we considered whether policymakers, corporate buyers, thought leaders, and market-makers should broaden their focus to all technologies and options for reducing greenhouse gas emissions.

That discussion begged a question we have grappled with for the better part of the last ten years in this Forum – what is "clean energy"? Smart and thoughtful people disagree, but the North Star of decarbonization has become a virtual consensus. Consequently, we are seeing a growing view that all forms of zero-carbon generation – as well as enhanced, system-based demand-side approaches -- must be optimized and utilized. This led to robust discussions about the role of nuclear, fossil energy with carbon capture, and "other renewables" (e.g., hydropower, biomass, and geothermal). We were focused on getting beyond predicate technology-based biases to grapple with the even tougher questions of creating an energy sector that provides all the critical services and benefits we need while respecting climate science, the interests of a diverse and unequal economy, and the equities of future generations.

Beyond electricity, we looked hard at other parts of our economy that we must decarbonize – including transportation, heat, and industrial processes. And recognizing that there is a very real chance that progress in decarbonizing the energy system might not keep up with science-based timelines, we took a hard look at an emerging set of tools that might be needed. Direct air capture of CO_2, the use of "negative" emissions technologies such as biomass generation with carbon capture, and new approaches to using hydrogen are likely to be needed. How we accelerate not just the technology development, but the policies and market mechanisms that can bring those tools to market was the focus of our discussion.

As always, we left Aspen with greater understanding of our challenges and a sense of optimism that we can in fact achieve our great ambition. We thank the Aspen Institute and our great participants.

Roger Ballentine

Jim Connaughton

EXECUTIVE SUMMARY

The latest Intergovernmental Panel on Climate Change (IPCC) report has intensified the focus on measures to achieve deep decarbonization. For the United States, most experts say that, if the aim is to be on a 1.5°C pathway, the United States must achieve a net-zero carbon profile economy-wide by around mid-century, going negative thereafter. There are five basic elements of achieving deep decarbonization of the energy system: (1) employ energy efficiency to the maximum degree; (2) decarbonize the electricity supply; (3) electrify other sectors as much as possible, including heat, transportation, and industrial processes; (4) use zero-carbon fuels for the areas that cannot be effectively electrified; and (5) use carbon capture, utilization, and storage (CCUS) and carbon dioxide removal (CDR) for areas where fossil fuels are still needed and for achieving negative emissions.

Clean energy has been growing in the United States and around the world, but to achieve deep decarbonization, much, much more is needed. While the shares of different fuels in the U.S. and global energy mix have changed dramatically over the past couple of centuries and even the past few decades, the share of global energy supplied by clean energy over the last decade has remained flat, as clean energy growth is only just keeping up with total energy growth, including new fossil fuel generation growth. Furthermore, from a climate perspective, what matters is not shares but the absolute levels of usage and emissions – and from that vantage point, the changing energy picture has been less a story of transitions than of additions, with any changes in shares swamped by growth in overall energy demand. A true energy transition to achieve deep decarbonization will require not just additions of new incremental capacity but also subtractions of the carbon-intensive parts of the current energy system. This is not yet happening globally, though the United States may be experiencing some transition, with flattening demand from energy efficiency, growing use of natural gas, declining coal generation, and a move to lower-carbon sources, including increased deployment of solar (distributed and utility-scale) and a growing role for battery storage (both driven largely by plummeting costs).

The increased attention to deep decarbonization has focused the debate around whether the goal is 100% renewables (mostly solar and wind) or 100% zero-carbon. Studies looking at deep decarbonization scenarios for the grid have generally found that the availability of some kind of firm, zero-carbon power (e.g., nuclear, hydro, geothermal, biomass, fossil with CCUS, hydrogen, long-duration storage) reduces the costs and risks of decarbonization, particularly as the penetration of variable renewables increases. This is largely because of the variability – particularly the seasonal variability – of wind and solar. While the country is still at such low levels of renewables penetration that the debate about what to do when penetrations get really high can seem somewhat academic, policies adopted now could either open or foreclose technological decarbonization options. The likely need for zero-carbon dispatchable resources in a decade or two suggests that it is better to keep options open. Still, large corporate buyers, who have been among the biggest drivers of clean energy in recent years, have focused their purchasing almost exclusively on renewables. This is partly because wind and solar are easier in terms of public opinion, the risks of NGO criticism, and accounting, but it is also partly due to the fact that most companies are seeking only to match their amount of energy usage, not to actually power their facilities 24/7 with electrons from zero-carbon power sources.

Because of the changing expectations of customers (big and small), new technologies, and overarching objectives such as decarbonization, states are beginning to rethink what the electricity distribution grid looks like and how to plan it. Growing numbers of distributed energy resources (DERs) are changing the needs and capabilities of the grid, so some states and regulators are starting to look at distribution grid planning processes that encourage DERs where they are helpful to the overall system and that compensate DERs for the value they provide. There are technological opportunities behind, at, and in front of the meter, including automated interoperable home devices, smart meters, smart inverters, and high-resolution sensors. Utility investments in DERs and grid modernization, however, are hindered by antiquated cost-effectiveness tests and accounting rules, such as ones that favor capex over opex and thus limit utilities' incentives to invest in software and cloud services to utilize the data being collected by smart technologies. Some critics have also argued that only the rich benefit from DERs while the poor subsidize them, but community solar is one way of democratizing access to clean energy. Technologies such as blockchain can allow people to use their DERs to provide peer-to-peer energy transactions, though there are some policy, technology, and cost barriers to that at the moment.

In the U.S. wholesale electricity system, competitive markets have fostered innovation, lowered prices, and facilitated renewables deployment. Technological advancements in storage, demand response, and energy efficiency, however, are reducing the need for instantaneous matching of supply and demand and for constructs such as mandatory reserve margins and optimal capacity mixes. The U.S. Federal Energy Regulatory Commission (FERC) plays an important role in removing barriers to the participation of storage in wholesale markets, streamlining processes to better integrate renewables, and breaking down barriers to entry for aggregated DERs, but FERC is facing challenges regarding how to value the externalities (e.g., carbon, resilience) of various types of power sources. As those externalities go unvalued at the federal level, states are increasingly stepping in with out-of-market supports for local sources of generation. It is a question of perspective whether these supports are distorting the market or filling gaps in it – and whether imperfect markets or imperfect regulations are better for meeting the range of societal goals.

While much of the decarbonization focus tends to be on electricity, transportation has surpassed it as the largest contributor of GHG emissions in the United States. With respect to light-duty vehicles, a lot of decarbonization efforts are focused on battery electric vehicles (EVs), sales of which are growing rapidly. Some major manufacturers have announced plans to convert their fleets from internal combustion engines to electric. Other key accelerants for EV adoption could include the deployment of charging infrastructure, policy incentives, the ability to monetize the grid benefits provided by EVs, and the rise of shareable autonomous mobility-as-a-service. Potential headwinds to EV adoption, meanwhile, include the availability of materials for batteries, restrictions on direct sales to consumers, and transportation infrastructure that was not designed with a variety of vehicle types in mind. With regard to medium- and heavy-duty vehicles, there are many technological and operational opportunities for improving truck efficiencies, and batteries and hydrogen fuel cells could be options for decarbonizing trucks' energy needs. Air travel is where transportation fuel use is growing fastest, and there are opportunities for both incremental and transformational improvements in airplane efficiency, including better engines, design modifications to wings and propulsion systems, and reducing weight by using more carbon-fiber in frames. Finding low- and zero-carbon fuels for aviation will also be important, and batteries (for short-haul and potentially medium-haul trips), liquid hydrogen, and biofuels are all possibilities.

Beyond electricity and transportation, industry accounts for about one-third of global emissions, though it accounts for a far smaller fraction of global decarbonization effort. There are potential decarbonization solutions that cut across industrial sectors, such as more efficient motors, industrial CCUS, electrification, and zero-carbon hydrogen. Demand for materials made through low-carbon production could be advanced with protected markets created by government and corporate procurement programs. There are also demand-side ways to lower industrial emissions by reducing energy needs (e.g., through use of more efficient equipment and processes) and by necessitating less materials production (e.g., through business models that deliver services instead of stuff, recycling of construction and demolition waste, and substituting less carbon-intensive materials). The epicenter of efforts to reduce industrial emissions has to be the Gulf Coast, where Texas and Louisiana account for the vast majority of U.S. industrial GHG emissions and where billions of dollars are being spent on new petrochemical expansions and refining.

Across sectors, there will almost certainly still be lots of carbon-based energy for years to come. CCUS technologies will affect the ability of fossil fuels to participate in a deeply decarbonized world, while CDR technologies could prove vital to keeping atmospheric carbon dioxide (CO_2) concentrations within agreed-upon bounds. Carbon capture technologies can help decarbonize both the power and industrial sectors, though the particular capture technologies used (e.g., oxycombustion, solid sorbents) will vary by sector and facility. CDR solutions could include both biological approaches, which store carbon in forests, soils, and ecosystems, and engineered approaches such as direct air capture (DAC), which use chemical processes. DAC systems are currently limited by high costs and access to clean energy, but they might be able to piggyback on existing sources of low-carbon, low-temperature heat (e.g., geothermal and nuclear plants) adequate for regenerating the sorbents used in some DAC systems. To achieve scale, DAC and other CDR technologies will need government incentives, technological advancements, and early CO_2 utilization market opportunities that can increase near-term deployment and allow the technologies to move along the learning and cost-reduction curves. These utilization opportunities could include using captured CO_2 as a feedstock in products (e.g., plastics, nanofibers, fuels), to carbonate beverages, or for other purposes. Captured CO_2 can also be stored underground – the United States has plenty of geological storage capacity – or used for enhanced oil recovery, which involves both utilization and storage and which can produce oil with a much lower carbon footprint than a conventionally produced barrel.

To advance decarbonization of all these sectors and address the many difficult issues that deep decarbonization will raise, there is a need for new, broader, smarter, more significant policy approaches. Broadly speaking, options include policies to internalize the climate externality (e.g., carbon pricing), support innovation (e.g., R&D), provide information (e.g., labeling and certification), account for network- and systems-level effects (e.g., building codes), and deal with geographic spillover issues (e.g., carbon border adjustments). In addition, energy and climate policies have to grapple with the significant human, community, and social values that are at stake, which makes equity a vital part of the climate policy conversation too. Some policy options could have cross-sectoral application, while tailored policies may be needed to address barriers sector by sector. For instance, power sector policies could include energy efficiency standards, renewable or clean energy standards, cap-and-trade, and storage mandates. Policies to electrify other sectors could include performance standards (e.g., vehicle emission and fuel economy standards), building codes, and a shift from energy savings targets to carbon efficiency standards. Government procurement standards and infrastructure policies that can advance CCUS could help with industrial decarbonization. Policies and programs to help farmers increase soil carbon sequestration, lease land for renewables, and gain clarity about the roles of biomass and biogas could help in the agricultural sector. Likely, there will not be one big policy idea that drives decarbonization so much as a mosaic of approaches.

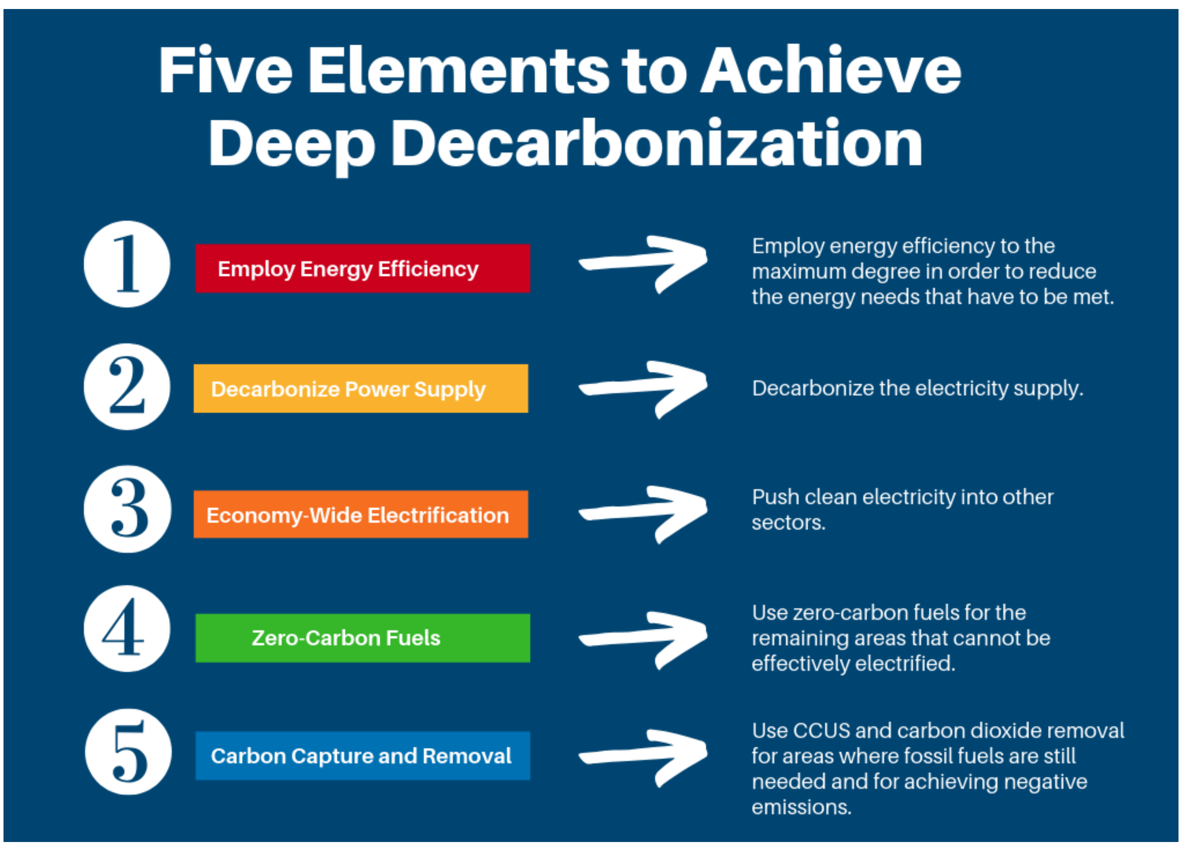
Fortunately, in both state and federal policy circles, climate change is receiving political attention that it has not had for years. At the state level, some clean energy ballot measures succeeded while others failed, some new governors have taken office with much stronger focuses on clean energy and climate change, several states have adopted or are in the process of considering their clean energy goals and the fate of existing coal plants, and some states have advanced efforts explicitly focused on capping emissions. At the federal level, the dynamics of the federal climate policy discussion have shifted as well. The Green New Deal has dominated the climate narrative, while some leading Republicans have begun pivoting the conversation on the right to a focus on solving climate change via innovation. There are still divides within each party, but there might be a fragile moment of opportunity to work on federal climate policy. Private-sector engagement with members of Congress will be important to pressure and educate all to find common ground and advance solutions. Climate advocates also need to put many different policy solutions on the table so Republicans and Democrats can find ones they both can agree on. The parties can build on the clean energy successes of 2018 (e.g., increased clean energy R&D funding, new incentives for CCUS and advanced nuclear) to achieve new policy wins, including ones focused on innovation, infrastructure, taxes, and perhaps other areas. Even if those policies are piecemeal measures, they can move things in the right direction and build a broader political foundation for future action. The key is to figure out the social and political alchemy that puts policy and technological solutions together in a way that gets broad enough support, creates a coherent and effective enough set of actions and capital deployment, and achieves enough progress in reducing GHG emissions.

DEEP DECARBONIZATION

Deep decarbonization is an economy-wide imperative, but the challenge of achieving the needed levels of global decarbonization across all sectors can seem daunting.

HOW TO ACHIEVE DEEP DECARBONIZATION

In general, there are five basic elements involved in achieving deep decarbonization of the energy system. First, employ energy efficiency to the maximum degree in order to reduce the energy needs that have to be met. Second, decarbonize the electricity supply. Third, push clean electricity into other sectors. Fourth, use zero-carbon fuels for the remaining areas that cannot be effectively electrified. Fifth, use carbon capture, utilization, and storage (CCUS) and carbon dioxide removal (CDR) for areas where fossil fuels are still needed and for achieving negative emissions.



Progress on some of these steps is further along than on others. With regard to energy efficiency, electricity demand is now generally flat in many developed countries, including in the United States, where most utilities are grappling with the implications of flat or declining sales. Decarbonizing the electricity supply has similarly grown more and more cost-effective in recent years, and utilities are increasingly moving in that direction both to cut carbon and to save money. Because of that growing cost-effectiveness, the electrification of other sectors is now more possible than even a few years ago, particularly with respect to pushing electricity into the transportation sector. On the other hand, there is still a great deal of work to do to develop competitive and effective zero-carbon fuels at scale, whether biofuels, hydrogen, or something else. Likewise, there is still a lot of work to do to develop competitive and effective CCUS and CDR at scale, but there have been some great things going on there, and some see cause for optimism.

DEEP DECARBONIZATION IN THE UNITED STATES

Analyses suggest that U.S. greenhouse gas (GHG) emissions have to be more than 80% below 2005 levels by 2050 to be on a 2°C pathway (assuming the rest of the world acts similarly) – and have to be net zero by around 2045 and negative thereafter in order to be on a 1.5°C pathway. Reaching those levels by 2050 while accounting for an expected doubling of U.S. GDP would require final energy demand to decline by between one-fifth and one-third due to energy efficiency. Emissions from the energy system will have to drop dramatically, though the makeup of the U.S. energy system will depend on factors such as how quickly other sectors electrify and the availability of natural sequestration and other negative emission technologies (NETs). The higher the level of emission reductions desired (e.g., for a 1.5°C pathway), the more essential direct air capture (DAC) and other NETs become.

As more sectors electrify, U.S. electricity demand is projected to rise significantly. There will also be additional electricity loads to power processes to decarbonize fuels and run NETs. Decarbonizing the power sector therefore may not just mean getting to 100% clean, but also doing so while significantly increasing capacity.

These analyses suggest that fossil fuels will see significantly reduced U.S. demand by 2050, due to energy efficiency and electrification of other sectors. That does not necessarily mean, however, that fossil fuels are dead. Fossil fuels, for instance, can make hydrogen very cheaply, to facilitate a hydrogen economy. Fossil fuels (with full carbon capture) can also help with DAC, which needs heat to work.

In pursuing deep decarbonization in the United States, it is imperative to keep in mind that climate change is a global problem and that decarbonization actions require global effort. All the global growth in energy demand is projected to occur outside of the United States and largely outside of the OECD countries. Many of the world's poorest people still lack access to decent quality electricity services. China, the world's largest emitter, has included a big renewables push in its 5-year plan, but it also has huge amounts of new domestic coal-fired capacity coming online, as well as a large amount that it is supporting around the world.

So seeking to meet decarbonization or equity goals has to be viewed in a global light, not in an overly U.S.-centric way. Analyses that focus just on decarbonizing the United States may prioritize investment in certain sectors or technologies, but those priorities might be different if the focus is also on rapidly bringing down costs so others can more easily decarbonize around the world. Germany, for instance, helped bring the cost of solar way down with its feed-in-tariffs. There could also be strategies worth focusing on because of the potential for spillovers of innovation and knowledge to other countries, including with regard to business models, financial structures, industrial designs, and other innovations. The lessons and technologies from the United States can help others avoid some of the mistakes made in building and regulating the U.S. energy system. That is not necessarily to say, however, that a decarbonization approach that is only useful in the United States should not be pursued. As the biggest historical emitter, some would argue the United States has an obligation to pursue such approaches anyway.

In addition, embedded energy and embedded carbon are important to keep in mind. It can take a lot of energy and carbon to produce some clean energy technologies. This may be less relevant when penetration levels are low, but if those technologies are to scale, then the embedded carbon has to be considered.

CALIFORNIA LEADING THE WAY

California can provide a valuable learning opportunity for decarbonization in the United States. As a leader in the space, it has discovered that the harder one works on and analyzes deep decarbonization, the more challenges are uncovered.

California has undertaken significant, decades-long efforts on energy efficiency – including promoting combined heat and power in the industrial sector and enacting housing standards to reduce demand for electricity and gas – which have led electricity demand per capita in California to remain flat for decades even as it rose markedly elsewhere in the country. The efficiency gains mean California needs a smaller volume of clean energy to meet its goals, and the state has taken aggressive policy measures to decarbonize its electricity sector. Prices for renewable energy contracts in California have been falling a little less than 10% per year and have gotten fairly affordable.

Even if California reaches 100% clean electricity, though, it would still miss its greenhouse gas reduction goals by a lot. Electricity is responsible for only about 17% of California's GHG emissions. Natural gas in buildings and industry accounts for more than a quarter. Transportation represents about 40%, and emissions from transportation have increased over the last few years, in part because of bad housing policy; the lack of affordable housing means working families have to drive for hours to get to work. California agencies are working to try to advance decarbonization in these other sectors. For example, over the last few years, the California Public Utilities Commission has directed utilities to spend about $1 billion on electrification of transportation, and utility plans have included a focus on the goods movement industry, especially around ports. The California Energy Commission has likewise called for net-zero buildings, pushing zero-carbon technologies such as rooftop solar and geothermal heat pumps.

TECHNOLOGICAL SURPRISES

Deep decarbonization of the U.S. and global economies will be a formidable challenge – one currently filled with great uncertainty about technological pathways and costs. For zero-carbon technologies to make a big dent in emissions levels, they have to become almost ubiquitous in a relatively short period of time, which will require harnessing the power of markets and greed to get capital flowing. It is hard to say whether all the technologies needed to tackle the climate crisis already exist. Either way, innovation would certainly make tackling the challenge easier.

Conversations can sometimes drift to preferred technologies, but there are many ideas out there, and there will be more over time. Experts try to extrapolate the future from what they currently see, but forecasts that look through the lens of today often miss what can be. There is no point in predicting technologies decades out. Technological innovation can bring surprises, and there are always people out there thinking about the impossible. Technologies can produce unexpected futures – sometimes ones that no one or only a few can see. Few investors, though, want to invest in a future they cannot see – which risks investments flowing only into technologies that bring incremental and not disruptive change. Public policies and private-sector investments should try to create optionality – proliferating potential options instead of trying to close them down.

Few investors, though, want to invest in a future they cannot see – which risks investments flowing only into technologies that bring incremental and not disruptive change.

CLEAN ENERGY TRENDS

Clean energy has been growing in the United States and around the world, but to achieve deep decarbonization, much, much more is needed.

ENERGY ADDITIONS, NOT TRANSITIONS

Shares of primary energy in the United States and globally have changed dramatically from around the beginning of industrialization to the present. For instance, in 1800, both in the United States and globally, almost 100% of energy came from biomass, whereas biomass accounts for only about 10% globally now (and less than that in the United States). Energy generated from coal grew, peaked in the early 20th century (at more than 40% of global energy), and has since declined to about 28%. Oil and gas, which have mostly been post-World-War-II fuels, peaked at over 60% globally and have now come down to about 52%. There have been many such ebbs and flows through transitions over time, both in energy broadly and electricity specifically. The share of global energy supplied by clean energy over the last decade, though, has remained flat, as clean energy growth is only just keeping up with global economic development.

The environment cares not about shares or new additions but rather about the absolute levels of usage and emissions.

Furthermore, the environment cares not about shares or new additions but rather about the absolute levels of usage and emissions. Historically, energy growth in absolute terms has almost always been continuous, with any changes in shares swamped by growth in overall energy demand. Biomass, for example, may have seen its share decline from 100% to 10% since 1800, but the actual amount of biomass used has tripled. Likewise, even as coal's share has declined, the amount of coal actually used has grown eight-fold since the early 1900s and 60% since the year 2000. The changing energy picture has been less a story of transitions than of additions.

The United States electricity system may be experiencing some degree of transition, with flattening demand from energy efficiency, a move to lower-carbon sources, growing use of natural gas, and declining coal generation. That is certainly not the case globally, though, and global energy consumption is projected to grow substantially in the years ahead under existing policy pathways. A true energy transition to achieve global deep decarbonization will require not just additions of new incremental zero-carbon capacity but also subtractions of the carbon-intensive parts of the current energy system.

RENEWABLES & THE CHANGING U.S. ELECTRIC GRID

The U.S. electric grid is changing tremendously, transitioning from a centralized, hub-and-spoke model to a more decentralized, mesh-network system. Consumers are driving many of these changes, motivated by desires such as security, resilience, clean energy, and price certainty. At the same time, the mix of resources on the grid is also changing, driven by low natural gas prices, environmental regulations, and massive cost declines in renewables.

The U.S. Energy Information Administration estimates that almost a quarter of U.S. generation capacity additions in 2018 were from solar, second only to natural gas. Most of that solar was utility-scale, but a sizable portion was distributed. In 2017, distributed solar accounted for about 1% of U.S. electricity actually generated, as did utility-scale solar, both of which are quite small compared to natural gas (about 32%), coal (about 30%), and nuclear power (about 20%). Still, between 2007 and 2017, the United States went from about 72% fossil fuels to about 61%, while solar grew almost 60-fold over the course of those 10 years.

The costs for solar have plummeted. In 2008, the levelized cost of energy for solar was around $140/MWh, but it was down to around $40 in 2018 – an 11% annual drop. Wind's costs dropped around 5% a year. The levelized cost of natural gas combined cycle plants, which dropped about 4% a year, is now slightly higher than solar and wind, and coal plants, nuclear plants, and natural gas peaking plants are out of the money. Looking at a different metric, the average deployed cost for solar in 2012 was around $1.93/watt for utility PV, versus around $1/watt now. Conservative estimates indicate that utility-scale solar will decline to around $0.70/watt within 3-4 years.

Between 2007 and 2017, the United States went from about 72% fossil fuels to about 61%, while solar grew almost 60-fold

Solar's costs have been on this path in part because cost declines follow volume increases, and there has been massive Asian investment in production. Asia leads the world in global clean energy investment, accounting for about half, which means Asia has been a key driver of scale in the clean energy world. In addition, there has been lots of value engineering in the industry to bring costs down across the whole value chain, not just in the module costs.

Accordingly, utility-scale solar power purchase agreements (PPAs) over the past couple of years have been coming in at costs that beat new-build natural gas plants. In some cases, the costs of new investments in renewables are also cheaper than the variable operating costs of existing fossil-fuel investments; those "shutdown economics" are the engine driving retirement of coal plants, as capital is being put to work to lower customers' bills in a flat-demand environment. Renewables now make good business sense, satisfying a market need for carbon-free emissions, which consumers increasingly demand, while also having zero fuel cost, which removes a lot of risk from operators' balance sheets.

Storage, too, has seen enormous cost declines – even more rapid and substantial than for solar PV modules – and the role of storage has accordingly been growing in various parts of the grid. As storage becomes bankable and investible, it will not only change when renewables are available but could change the entire management of the grid. For instance, the infamous "duck curve" in California has been mitigated to a large extent by storage. As discussed later, electricity storage could also upend the structure of electricity markets, which are designed to balance in real time but could instead become more like normal markets.

Solar is the catalyst and storage the enabler of renewables' economic power. Renewables and storage are becoming the first choice of many seeking power – driven not by morality or environmental concern but by cost declines. Many utilities therefore expect the next decade will see continued significant investment in and growth of renewable energy, even with federal tax credits sunsetting. Forecasts based on existing policies project natural gas, solar, and wind continuing to capture almost all new capacity additions.

There are some headwinds facing renewables, though. For instance, virtual PPAs tend to have 10-15 year contracts instead of the old 20-35 year contracts, which adds risks that increase the cost of capital and reduce the number of investors willing to invest. The bankruptcy of PG&E in California will create additional headwinds for this year's renewable energy development and contracts, as investors are terrified that PPAs will be abrogated. As a result, virtually all new plants – not just in California – will be contracting with corporations and communities instead of utilities and will be demanding new collateral and backstops. Other headwinds for renewables deployment come from interconnection complications, security and cybersecurity concerns, and – particularly for the relatively new, burgeoning category of community solar – processes in need of streamlining. The current Administration's solar tariff had created headwinds too, but the markets now have largely worked around it to bring prices back down.

Solar is the catalyst and storage the enabler of renewables' economic power.

In addition, the cost of capital for utilities versus for independent power producers (IPPs) has not yet achieved parity. Utilities have very cheap debt and cheaper equity compared to IPPs. Utilities have a cost of capital around 5%, whereas IPPs have a cost around 7%, which is a vast improvement from where it was but is still higher. If the goal is to unleash trillions of dollars of investment in clean energy, reducing that gap to have fairer market structures would be one way to spur such investment. On the other hand, some feel that the gap in cost of capital is a feature and not a bug in the system, reflecting differences in the riskiness of the investment.

ELECTRICITY: IS THE GOAL 100% RENEWABLE OR 100% CLEAN?

Some stakeholders have been arguing very forcefully that clean energy includes only wind and solar. Other climate advocates argue that the focus should be on anything zero-carbon – adopting an approach that is more attribute-based than technology-based. This broader approach incorporates technologies that tend to complicate the politics on the left but improve politics on the right.

DECARBONIZATION CHOICES

Decarbonization options for the power grid include both variable, weather-dependent sources (e.g., wind, solar) and firm, dispatchable options (e.g., nuclear, hydro, geothermal, biomass, fossil with CCUS). Studies looking at deep decarbonization scenarios for the grid have found that the availability of some kind of firm, zero-carbon power reduces the costs and risks of decarbonization, particularly as the penetration of variable renewables increases. Part of the reason for this is the large variability of wind and solar – not just within a day but also across weeks and months – often in a way that does not match load. The wind blows more during some parts of the year than others, and the amount of sunlight varies seasonally as well, leading to multi-week or multi-month surpluses or deficits if the grid relied wholly on those resources.

This seasonal variability is a significant challenge, particularly since the currently available storage options tend to be more on the daily (or hourly) scale. Using batteries to capture and store seasonal surpluses for use during times of seasonal deficits, for instance, would be tremendously expensive, even assuming battery costs continue to fall sharply. It would also require huge amounts of storage capacity that would have very low utilization levels. Storage, of course, is not the only grid flexibility resource available. Other resources can also help to integrate variable renewables, including more transmission, demand response, having larger geographic areas to allow more smoothing of renewables, forecasting and improved scheduling, and more. All of these resources can help and can reduce costs, but many studies suggest that seasonal variability is still very hard to tame. Even assuming the existence of a seamless national grid that allows renewables and demand response anywhere to serve load anywhere, the costs of moving to 100% renewables are projected to be very high.

Backing off from 100% to 80% renewables would still be very expensive, but much less so, as some other resource(s) would be operating to fill the gap. It should be noted, though, that some dispute the assumptions underlying projections that high levels of renewables penetration will be costly, pointing to studies and real-world examples of high penetrations with excellent economics. Either way, the issue is not as simple as figuring out how to close the gap of that last 20%. By the time renewables penetrations get that high, cost-effective options for the remainder may be foreclosed due to low utilization. In other words, the zero-carbon resources that could be used to fill the gap (e.g., storage, nuclear, CCUS) are generally high capex, but at 80% renewables penetration, they would be utilized for a low number of hours, which may make them uneconomic. There may be a need to ensure adequate market share or support to make them economic. Waiting to address the gaps until renewables are at much higher penetration levels also risks losing the existing nuclear fleet, which would be a loss of terawatt-hours of carbon-free generation.

There is a debate about whether to invest in keeping zero-carbon nuclear plants alive for longer or investing that money instead in cheaper options that achieve more reductions, such as energy efficiency. Given the scale of reductions needed for deep decarbonization, however, some would argue that all zero-carbon resources are needed, quickly, and at much greater scale.

Currently, there are precious few zero-carbon dispatchable power resources that are scalable, rampable, site-able, and socially acceptable. The need for zero-carbon dispatchable resources in a decade or two means the growth of such technologies and the development of better options and solutions need to be supported now.

Nuclear fission, hydro, and long-duration storage (whether batteries, hydrogen, subsurface pumped hydro in depleted reservoirs, or something else) may all be options, and investors are exploring some of them. Investors are also exploring taking the lessons and technologies from the shale boom and applying them to geothermal. In addition, there are technologies, such as the NET Power demonstration plant in Texas, that could provide cheap gas-fired power with full carbon capture. Biomass could be an additional option; there are many controversies and assumptions around how to treat biomass and how scalable a solution it really is, but given the scale of the decarbonization challenge, there is a clear need to talk through these issues and figure out some resolution. There is also a limited supply of biogas – captured methane from cattle, dairies, landfills, and the like – so there are debates about whether to use it for electricity or to put it in pipelines for use as natural gas.

The need for zero-carbon dispatchable resources in a decade or two means the growth of such technologies and the development of better options and solutions need to be supported now.

Hydrogen, too, could prove to be a powerful solution. Natural gas combined cycle plants, for instance, could be retrofit to run on hydrogen, and hydrogen – if cheap enough – could then decarbonize the power sector in one fell swoop, utilizing rather than stranding trillions of dollars of assets that are already deployed. To make it even cheaper, one could use carbon dioxide (CO_2) to clean up sour gas, which is cheaper than regular natural gas, and feed that into the reforming process – with the CO_2 sequestered – to produce hydrogen.

Whether the ending point is 60% or 80% or 100% renewables, that is still far from the current reality, so there is no reason not to encourage rapid deployment of renewables. Given the impossibility of predicting politics and technologies decades from now, coupled with the urgency of rapid action and the fact that climate change is a stock problem (involving the aggregation of greenhouse gases in the atmosphere), many would argue that taking action now is more impactful than arguing about where it is possible to get to in the future. That same line of thinking, though, suggests that it makes sense not to broadly foreclose technologies up front. Instead, markets and policies should keep options open and let technologies develop. In concept, something like laddered auctions for all carbon-free resources could enable saving the most carbon with the fewest dollars in a technology-neutral way, though the details will matter a lot in terms of how resources are compared to each other.

Indeed, while there is still a vocal contingent on the left advocating for 100% renewables, many within the mainstream environmental community and among the climate leaders in Congress appear to have moved beyond the idea. (The Intergovernmental Panel on Climate Change's 1.5°C report seems to have flipped a switch.) There have been a few state bills recently to go 100% zero-carbon that have been supported by mainstream groups, and a couple of states have now adopted a shift from a renewables-only focus to a broader zero-carbon focus. It will be interesting to see if this pattern continues in the near future as states make decisions about what to do with their expiring Renewable Portfolio Standards (RPSs).

CORPORATE BUYERS

One of the biggest drivers of clean energy in recent years has been corporate purchasing. Large buyers have been led by the commercial and industrial sectors, but there are also buyers among universities, cities, and others. For many, climate change is the driver for their focus. For others, climate is just one driver, alongside issues such as air pollution, water, resilience, and security. This purchasing, however, is almost exclusively focused on renewables, not the broader set of zero-carbon resources.

There are variations in corporate goals. Some have committed to be supplied by 100% renewable power (which includes grid-connected renewables). Some have committed to drive production or procurement of a certain amount of renewables – seeking to have a very specific, material impact on the grid, even if the company does not get to claim credit for consuming the clean electrons. Many others have committed to actively procuring 100% renewable power; such procurement goals enable companies to claim to be carbon-neutral by purchasing, somewhere in the world, an amount of energy and renewable energy credits (RECs) equivalent to their own energy usage. More than 160 companies globally have 100% renewable energy goals – partly because such goals are relatively simple (contractually) to achieve, especially for big companies, who can arrange big PPAs and utilize green tariffs. The goals are also easily marketable concepts and illustrate to stakeholders that the companies are taking pains to manage their environmental impacts. These goals have impact; if all RE100 members achieved their goals, it would bring on 45 GW of renewables in the United States – the same amount brought on by all RPS compliance between 2011 and 2017. That is a substantial scope of demand. There could be even more demand but for some existing headwinds, such as the lack of regional transmission organization (RTO) coverage in some regions and the need for better marketplace tools and constructs than the virtual PPAs that currently dominate.

One of the biggest drivers of clean energy in recent years has been corporate purchasing.

In addition, many corporations have set absolute GHG reduction goals, which convert renewable energy from an end in itself to a means to an end. Others are pushing the envelope further, looking at a more complex goal of sourcing 24/7 carbon-free energy to power their operations globally. The 24/7 goal involves looking at all corporate locations and all hours of the year, adding up the underlying carbon-free content on the grid and hourly production from corporate PPAs compared to real-time corporate energy needs, and figuring out how to fill the gap that remains with technological, transactional, and policy innovations. There is currently no product in the United States for 24/7 clean power. Being able to claim 24/7 clean power could require upgrades to the REC paradigm to take account of the temporal aspects of the energy system that are not reflected in RECs today.

There are other problems with the current REC market as well. For instance, some corporate buyers argue that the United States should have two different instruments – one for producers aiming to satisfy RPS-type compliance and one for consumers looking to be able to claim something about the cleanliness of their energy usage – rather than the single REC that exists now.

Some companies are struggling with setting their goals, trying to figure out whether to aim for renewable or zero-carbon resources. Greenhouse gas and renewable energy accounting rules complicate large buyers' efforts. There are many guidelines and requirements issued by agencies and NGOs, and there are tons of NGOs ready to publicly identify big brands they suspect of greenwashing. Some companies are more sensitive to the wrath of NGOs than others. Accordingly, since PPAs for wind and solar are easy – and eliminate worries about lifecycle analyses, where bio-stocks are grown or burned, and other such complexities – many companies play it safe and focus solely on wind and solar, pushing the challenges of intermittency, grid smoothing, and so forth onto others to figure out. Relatedly, certification may be a hurdle to attracting interest among electrical buyers in purchasing electricity that is zero-carbon due to CCUS – to give buyers comfort that what they are buying is truly zero-carbon. On the other hand, an e-certificate that PJM adopted back in 2010 that allows for direct procurement of zero-emission power from any nuclear plant has gone unutilized.

ELECTRICITY: THE DISTRIBUTION GRID & RETAIL MARKETS

There has been a blurring of the line between retail and wholesale markets in recent years, with more interaction between them. This is a period of dynamism and evolution in how people think about retail markets and the distribution grid, the technologies available on the distribution grid, and the range of players involved – all of which affect how the distribution grid is regulated and planned in each state.

STATES & REGULATORS

The distribution grid is the area of electricity regulation where angst appears to be most pronounced. The third-rail topics for regulators (e.g., rooftop solar, net metering) tend to focus on end-users, especially residential and small commercial. It can be a challenge for regulators to both encourage those pieces of the market and make them fit into the larger objectives of least cost, reliability, carbon reductions, and the like.

States that are leading in efforts to reimagine the distribution grid to be cleaner and more distributed are doing so in very different ways.

Because of the changing expectations of customers, new technologies, and overarching objectives such as decarbonization, states are beginning to rethink what the distribution grid looks like and how to plan it. States that are leading in efforts to reimagine the distribution grid to be cleaner and more distributed are doing so in very different ways. California, for instance, remains a very vertically integrated marketplace, whereas New York is looking to disrupt the utility and turn it more into a platform manager. Many more states are getting involved too, at the beginning of their journeys of looking at how the distribution grid should evolve. Given utilities' political clout in many states and the significant momentum behind how investor-owned utilities currently operate, more states and regulators are likely to pursue a process of nudging, guiding, and constraining existing models to achieve clean energy goals than to wipe the slate clean and start over from scratch.

Distribution grid planning processes are starting to get more attention in several states. Growing numbers of DER technologies are changing the needs and capabilities of the grid, and data on locational differences is starting to become more important. Well-located microgrids and DERs can help alleviate the growing unreliability of the electricity grid, to the benefit of customers, developers, and utilities. Accordingly, some states and regulators are starting to look at the distribution grid in a more detailed, information-driven, transparent way to encourage DERs where they are helpful to the overall system. Some regulators are looking at how to bring these processes more into the open – more like integrated resource planning processes – to explore and compare various options for addressing distribution grid needs, including through on-site generation, storage, demand-side management, and targeted price signaling. The National Association of Regulatory Utility Commissioners and the National Association of State Energy Officials are in the midst of an 18-month process to figure out how to create state-specific frameworks to do that kind of distribution system planning and incorporate it into resource planning.

Unleashing DERs would also be bolstered by building in various externalities, such as the value they provide in terms of resilience. New compensation regimes are cropping up, replacing net metering with value-of-DER (VDER) programs. In states such as New York, however, VDER programs are not capturing social, health, or environmental externalities and are undervaluing distributed solar, which means fewer projects will get built. Beyond VDER programs, getting externalities accounted for in the regulatory process may well hinge on changing the definition of what counts as "just and reasonable" utility expenses. At the same time, distribution system policies should aim to properly value the services the grid provides – as opposed to letting people free-ride on the system. They should also seek to balance investments in DERs with the need for investments that achieve the biggest bang for the buck in terms of emission reductions, which tend to be through large-scale renewables deployments.

TECHNOLOGIES & UTILITY INVESTMENT

The energy industry has largely been a 20th century, analog industry, but information technology is making rapid inroads, particularly on the distribution grid and in retail markets.

Behind the meter, home devices could have a large impact. Smart thermostats are just the beginning. Currently, devices and appliances in homes do not talk to each other, but the voice control devices that are now propagating quickly in homes could be the ones that link them all up. Controlling things by voice through smart home hubs can reduce energy consumption and give people more control. The biggest difference, though, may be in processes that will be automated in the background, such as coordinating devices and appliances automatically in response to a utility's peak pricing or demand response alert.

Regarding the meter itself, advanced metering infrastructure (AMI) enables time-of-use (TOU) rates to smooth load curves and allow better integration of distributed energy resources. Many states still have not approved AMI, however; with all the talk about a smart grid, many states do not even have smart meters.

In front of the meter, innovation is needed in distribution grid hardware. Many components have not changed much since the days of Westinghouse and Edison, but now there are opportunities related to technologies such as smart inverters, solid state transformers, and sensors. High-bandwidth, high-resolution, high-reliability sensors, for instance, could provide much needed visualization of the grid at a level of fidelity that many people want but does not yet exist.

Some utilities are leading the way on DERs, grid modernization, and decarbonization, but antiquated cost-effectiveness tests and accounting rules hinder the efforts of many utilities. For example, for most resources on the grid, the system spreads the costs over all users, but for energy efficiency and DERs, cost-effectiveness tests place heightened attention on avoiding cross-subsidization. In addition, despite the growing move in the economy to cloud-based services, utility accounting rules favor capex over opex – which means a utility could earn a return if it buys its own servers and runs software on them (capex) but would only get cost recovery if it hires a company to use cloud services (opex). Likewise, utilities have more incentive to build a peaker plant (capex) than to use technology to network together tens of thousands of homes to reduce load (opex). As a result, utilities tend to have lower adoption of data science technologies, and they generally have done very little with the data gathered from AMI. They also tend to keep data bottled up that reveals the overbuild of assets – even if that data would be useful to regulators and third-party service providers – because not building anything new for a couple of decades does not yield a good rate of return for utilities. Regulators not only ought to include digital infrastructure as part of the rate base, but should also change the broader system of rewards based on capex, as it is not yielding the desired behavior and goals. Some states, for instance, are looking at performance-based ratemaking.

COMMUNITY SOLAR

Residential customers want more clean energy. Currently, millions of households are paying more for renewable energy. That is a base that is already saying it wants to support clean energy and will actually pay more for it. That base is a distinct minority, though. Mitigating climate change will require democratizing access to clean energy. The answer to cross-subsidization concerns – the argument that the rich benefit from DERs while the poor subsidize them – is not to restrict DERs but to give poor people access. Community solar is one way of accomplishing that.

Community solar barely existed before 2015, but it crossed 1 GW of capacity in 2018, having doubled in capacity each of the last few years. Projections suggest that by 2030 it could reach 56 GW – or 84 GW in a more aggressive case – reflecting tens of billions of dollars in investment. Utilities have begun realizing that they need to offer their customers more choices, so there have been some utility-led community solar models. There are also models in states that are run by third parties, interfacing between customers and utilities.

Mitigating climate change will require democratizing access to clean energy.

More than 40% of people who sign up for community solar do so primarily to help the environment, while more than a quarter do so for financial reasons. (Almost 30% are motivated to sign up for both reasons.) To make going through the process of signing up for community solar worth it, people have generally said they want to save about $15, or about 10%, on their electric bills. On the other hand, some people choose not to sign up for community solar because they do not want a cancellation fee or because they reject the notion of long-term contracts. Another key constraint in signing people up for community solar – one that runs counter to the desire to democratize clean energy access – is the requirement for customers to have high FICO credit scores, but there are companies working to find better metrics that will broaden the number of community solar customers.

PEER-TO-PEER ENERGY

Energy could operate in a transactive model, similar to AirBnB for lodging. AirBnB is a digital platform that connects people who want somewhere to stay with people who have a place to offer, and AirBnB gets a service fee for the value it creates and delivers by serving as a platform for the exchange. Homeowners with a spare room can now monetize what was previously an underutilized asset. Digital platforms greatly reduce the costs of transactions to monetize excess capacity in assets, enabling more people to engage in mutually beneficial exchange. As the distribution grid digitalizes, the reductions in transaction costs could similarly change energy asset ownership and use patterns.

A homeowner with residential rooftop solar, for instance, could use unutilized excess capacity to sell power to someone else. One could imagine a retailer selling a homeowner a rooftop solar power system, perhaps along with an electric vehicle and a smart inverter, and allowing the homeowner to include their own preferences regarding the electricity price below which they want to charge the vehicle or the price above which they want to discharge the vehicle battery and sell the power to someone else. The vehicle battery too then becomes an asset with previously underutilized excess capacity. This could become a rich, vibrant retail market, capturing disaggregated resources and using automation to enable asset owners to transact with each other, while still being connected to the grid. The distribution utility would serve as the grid services platform coordinator, receiving a fee for that service.

It is important to note that, in at least some states, this approach would currently be illegal, while in many other states the legality is, at best, ambiguous. Policies will need to change to enable this kind of future distribution grid. In addition, the technologies to realize this vision do not yet exist, at least not at the right price. The potentially disruptive technology of blockchain, for instance, creates the potential to fuse physical control and financial exchanges on a peer-to-peer basis in a transactive platform, while addressing cybersecurity and data ownership issues, but it is still in its infancy in the energy space – though it is beginning to emerge rapidly in Europe and elsewhere.

ELECTRICITY: WHOLESALE MARKETS

There are things that happen in wholesale markets that even many people in the energy world do not understand; it may be that no one truly understands all the different facets of wholesale markets. The wholesale system could play an important role in decarbonization, though, and has been a signature achievement of the country and a model for the world.

CHANGING REALITIES OF WHOLESALE MARKETS

Wholesale power markets supply more than half of the world's electricity, and their share is growing. Competitive markets foster innovation, technological access, and lower prices. Competitive markets have also been a key part of the U.S. renewables story; it is no accident that most corporate renewables purchases (and the majority of all renewables) have occurred in organized markets. Markets can help advance decarbonization, if appropriately structured. In Europe, for instance, the market factors in the carbon trading price, which has risen substantially recently, leading several countries to decide to phase out coal. Some countries, such as Ireland, are putting their ancillary service markets on the top of the stack, creating access to new market products that better value flexibility.

Energy is increasingly storable, and as energy storage grows, the need to have an instantaneous match of supply and demand shrinks.

There are, however, never perfect markets or perfect capital allocation under a regulatory regime, and wholesale electricity markets are far from "free" markets. They involve a commodity that needs to be produced when it is consumed, with no tolerance for shortages and no ability to store at large scale. These realities have bound how wholesale markets are constructed and the regulations needed around them, such as mandatory reserve margins. These constructs and regulations, in turn, are often predicated on old technologies. For instance, the basis for U.S. capacity markets is a theory of peaker plants and an optimal capacity mix, and the requirements for resources in capacity markets are often designed for resources such as gas peaker plants.

These realities are starting to change, though. Energy is increasingly storable, and as energy storage grows, the need to have an instantaneous match of supply and demand shrinks. Likewise, technological advancements – including in storage, demand response, and energy efficiency – are undermining the theory of an optimal capacity mix and are turning technology-specific market requirements into antiquated barriers. Current assumptions that market participation is primarily from the supply side – assuming that generation follows load – could change in the future as utilities could become sources of demand flexibility, which could in turn affect market structure and price formation. There are disruptive and transformative changes coming on the demand side that may not sit in the wholesale market world but will certainly influence it.

In addition, the inputs to wholesale market models are important and have to accurately price the energy in the market. That may not be happening today. For instance, PJM first implemented locational marginal pricing (LMP) around the turn of the century using the then-available computing power, which necessitated some shortcuts. Security-constrained economic dispatch with LMP pricing is a good thing, having vastly improved the efficiency of dispatch, but the PJM pricing model could be much more accurate now given current computing capabilities. As a consequence of the under-valuation of energy in the markets, resources are becoming more reliant on PJM's capacity markets. This is not ideal for resources that get most of their value from energy production (e.g., renewables, nuclear).

THE ROLE OF FERC

Market operators around the world are watching the U.S. Federal Energy Regulatory Commission (FERC), and U.S. decisions about the structure of wholesale markets will reverberate across borders.

FERC can play an important role in reducing greenhouse gas emissions. For instance, FERC put out two significant rules within the past year – Order 841 and Order 845 – to remove barriers to storage participation in wholesale markets and to streamline the interconnection process to better integrate renewables. FERC has also approved proposals from RTOs and Independent System Operators (ISOs) to better integrate renewables into their markets. In addition, FERC is in the process of a rulemaking to break down barriers to entry for aggregated DERs, to make sure they are compensated for the value they provide.

FERC is facing many challenges regarding how to value the externalities of various types of power sources. To date, the objective function for wholesale markets has been to achieve reliability at least cost, but there are many different policy desires that consumers and policymakers are now trying to get from power markets. Externalities from power production are now more important than ever – whether carbon, resilience, or something else – but they currently go unpriced in wholesale markets. The most visible manifestation of this was in 2018, when the Department of Energy (DOE) submitted a Notice of Proposed Rulemaking (NOPR) to FERC about the supposed values of on-site fuel at coal and nuclear plants, for which those plants ostensibly were not being properly compensated. The record did not support compensating those externalities, as there was no threat to grid reliability or resilience from the retirement of those plants, and there was no particular value to the on-site fuel. FERC therefore rejected the NOPR. FERC did, however, open a resilience docket to explore what grid resilience actually is, whether there are current or potential future threats to it, and if so, what steps to take within markets to address them.

There are debates about whether the Federal Power Act (FPA) allows FERC to accommodate externalities such as zero-emission power. Some feel the FPA does not allow FERC to take them into account, while others argue that there is an absence of direction in the FPA regarding externalities, which means FERC could allow for accommodation of them. Congress, which generally exhibits a lack of understanding of wholesale markets, is starting to pay more attention in the wake of DOE's NOPR, and energy legislation in Congress could give cover to FERC on some of these harder questions.

STATES STEPPING IN

The fact that externalities that are important to consumers and policymakers are going unpriced has led states to step in to price them, creating tensions between state policies and markets. States are taking actions to prop up local sources of generation, whether for environmental, employment, resilience, community impact, or other reasons. States are looking to manage their own energy futures, but those actions affect markets. Many of these out-of-market payments or subsidies have been around for quite a while, such as state RPSs and the Regional Greenhouse Gas Initiative among the Northeast and Mid-Atlantic states. More and more state policies are being adopted, particularly around the fate of the existing nuclear power fleet. It is a question of perspective whether these out-of-market supports are distorting the market or filling gaps in it. Some think FERC should either apply a Minimum Offer Price Rule (MOPR) to everything in the market to wash out the various state policy interventions or apply MOPR to nothing. Others are trying to thread the needle to find a middle ground. This is a complicated, difficult issue.

Climate externalities are a clear manifestation of this tension. There are numerous proxy measures around pricing carbon in the absence of a federal legislative approach – unlike for sulfur dioxide and nitrogen oxides, which have well-defined markets and clear prices in federal programs. Absent a national price on carbon, states are filling the gap. In many states, carbon policy has largely been given over to air quality commissions – who do not intersect much with utility and energy regulators – which could create additional tensions between state policies and wholesale markets. No states, however, are internalizing zero-carbon attributes for all competitors – including nuclear, coal, and energy efficiency – and allowing competition among them. In addition, no states track carbon opportunity costs – tracking both carbon and dollars, such as through all-resource laddered auctions that would enable more reductions more cheaply (e.g., through energy efficiency).

States are looking to manage their own energy futures, but those actions affect markets.

The effort that is furthest along to incorporate climate externalities into wholesale markets is the New York ISO's development of a carbon adder. Even in a world with a robust carbon price, additional reforms may be needed to address climate change in organized markets. A carbon price is not a cure-all. For example, there is a need for a value on flexibility and fast-ramping capability in the market, to allow greater penetrations of renewables as well as dispatchable backup technologies.

Absent a solution, there is a risk that wholesale markets are moving in a direction where power prices are just a barometer for the amount of subsidies in the market. That would basically return things to the administrative model that the creation of RTOs and ISOs was established to rebuke. Others would be fine with a reversion along those lines. For instance, some argue that trying to optimize reliability, cost, carbon, and other societal desires within wholesale markets will just add more elements onto an increasingly complicated Rube Goldberg machine – and that perhaps it would be better to just admit that generation is being dictated by public policy (as is some demand-side effort) and go back to a planning model. An acknowledgement of a planning model could allow for more conscientious efforts, where the planning options are opened to public scrutiny and the tradeoffs are explained. Such planning or integrated resource processes are happening in many countries around the world.

Which is better for meeting the range of societal goals: imperfect markets or imperfect regulations? Things have reached something of an impasse, but continually getting stuck in a dynamic of states combatting FERC to accommodate or achieve state policy goals will erode the price signals needed to deploy the next generation of technologies.

TRANSPORTATION

Transportation has surpassed the electricity sector as the largest contributor of GHG emissions in the United States. Roughly 60% of the emissions from the transportation sector are from light-duty vehicles, just under a quarter are from heavy-duty vehicles, and almost a tenth are from air travel. Transportation remains overwhelmingly reliant on conventional fossil fuels, which is a problem in terms of climate, the environment, energy security, and fuel diversity.

Transportation has surpassed the electricity sector as the largest contributor of GHG emissions in the United States.

CARS

Investments are needed in all kinds of zero-carbon light-duty transportation technologies, including hydrogen fuel cells, but in terms of faster action on decarbonization, investment in battery electric vehicles (EVs) seems to be the direction things are headed. If a lot of hydrocarbon-based vehicles become electric and draw from a cleaner grid, emissions will go down.

EV sales are growing rapidly. It is now clear that there is significant consumer demand for these vehicles and that they can be produced and marketed profitably. EVs now are cool, which is important; people want to buy cars that go fast and look good, and there have not previously been enough of those in the EV space. Some EVs also have software updatability, which people want, as well as strong safety features. In addition, battery costs have plummeted at the same time that battery efficiencies have improved dramatically, giving EVs a lower price tag and longer range. Range anxiety has been declining among consumers anyway – leading some auto manufacturers to start retiring older hybrid models – and it often goes away entirely once people own an EV.

Some major manufacturers have announced plans to convert flagship vehicles in their fleets to electric drivetrains, while others are now envisioning 100% electric futures and have begun to cease developing any more internal combustion engine vehicles. The development period for a vehicle is typically around three to five years, so it is possible that within a few years, EVs may be the main choice available to consumers to buy. Even if the percentage of EV sales goes way up, it will still take many years for the overall percentage of cars on the road to catch up. Vehicles last for a long time, so it takes a long time to turn over the fleet of cars on the road. The average age of a car on the road in the United States is around 12 years, which already puts the date at 2030 for fleet turnover if every vehicle sold from here on was an EV.

Manufacturers' shifting product lines clearly would accelerate EV adoption. Another key accelerant for EV adoption will be deployment of needed infrastructure, such as for charging. Charging at home is relatively low-cost for those who already have an outlet for their clothes dryer; having an electrician flip it to provide charging outside as well is not that expensive. Not everyone has that option, though. From an equity perspective, there is a need to modify building codes to require the necessary wiring, panels, and infrastructure to enable charging options in new multi-family housing. Creating charging opportunities in existing multi-family buildings is harder and more expensive to address, but those buildings also account for far more of the building stock. If the goal is to get 100% zero-carbon transport within the next couple of decades, low-income populations will need access to zero-carbon transport options as well. Government subsidies, including tax credits, could be made into rebates and targeted at low- and moderate-income populations, instead of giving tax breaks to largely wealthy people to buy EVs.

Focusing on homes, however, may not be the right model for advancing charging infrastructure. As autonomous vehicles advance and mobility-as-a-service increases, the model of vehicle ownership may shift from single-vehicle ownership to a fleet model. If EVs are largely bought in fleets (for both commercial and personal transport), they will likely be recharged in centralized locations, which means efforts to put charging technologies in people's garages may end up becoming wasted investment. (The fleet model of EVs and mobility-as-a-service is also one of the main ways that EVs can be advanced among low- and moderate-income populations, who tend to be heavy users of ride-sharing.)

Fast chargers are another key aspect of infrastructure deployment, seeking to provide roadside options not dissimilar from gas stations. There is no business model at the moment for fast charging, however, because demand charges kill the economics. Demand charges make sense for industrial customers that have big spikes in their energy usage, but applying the same policies to direct current (DC) fast chargers is too onerous. Creative solutions are needed from utility commissions, utilities, and EV manufacturers. Car manufacturers, for instance, might have to give a little ground on vehicle-to-grid (V2G) technologies, so that the energy benefits are not just one-way affairs that cause congestion on the system. Currently, V2G would void manufacturer warranties, as frequent charging and discharging of the batteries could shorten their lives, but some players are starting to explore having utilities provide batteries as a service to get around that.

Indeed, utilities have a significant role in facilitating the transition to electric vehicles. Some co-ops, for instance, have decided to make it easier for their members to own EVs by giving members EV chargers and financing the costs for electricians to install them. Utility-supported (or perhaps utility-owned) public fast chargers can help reduce range anxiety among customers, and some utilities are looking at providing direct current as a service, stepping down to medium voltage DC and installing a charging station. One of the key issues regarding utility involvement with developing charging stations is whether and how regulators allow utilities to play in that space, and that remains a live regulatory issue in many states. Utilities can also adopt new rate structures, such as TOU rates, to encourage residential, commercial, transit, and fleet customers to charge EVs during off-peak hours (e.g., to use excess wind power at night).

Beyond charging infrastructure, there are other factors that could accelerate EV adoption. Ultra-lighting vehicles, for instance, could save on batteries. Aggressive EV policy innovations could also help, such as the feebates used in Norway to massively increase the level of EV sales there. The ability to monetize the grid benefits provided by EVs could likewise improve the economics. In addition, as noted above, the rise of shareable autonomous mobility-as-a-service favors electric vehicles.

While people are generally very bullish on vehicle electrification, there are potential headwinds that could slow adoption. A notable one is material availability for batteries. It is important to ensure that lithium and cobalt supply chains are robust in order to avoid supply shocks that could slow the industry. The Chinese have locked up a lot of the mineral deposits in Chile and elsewhere. More attention is needed to this national and energy security issue in Congress and among the various parts of the national security apparatus. On the other hand, some argue that new battery designs, such as solid polymer electrolyte batteries, could eliminate the reliance on minerals such as lithium and cobalt and instead use nothing scarce, toxic, costly, or flammable.

Restrictions on business models pose additional headwinds. For example, many of the new entrants in the emerging EV space are fighting against the franchise dealership model. That model tends to generate most of its profits from servicing vehicles, but EVs require far less servicing, so it is hard to make the business case for EVs in a franchise model. Many EV businesses are pushing to expand the sphere for direct sales to consumers.

This problem is not limited just to electric passenger vehicles on roads. Manufacturers of electric low-speed golf carts, club cars, and the like cannot sell them directly to consumers in the vast majority of U.S. states either. In addition, U.S. transportation infrastructure is not always well designed for such vehicles, which do 35 mph max. Infrastructure architecture, to the extent possible, should enable a variety of vehicles. There are many vehicles moving around in cities today, such as scooters, that were not originally intended. These low-end electric technologies could have big impacts on equity and carbon, if infrastructure and regulations do not create too many barriers.

TRUCKS

Heavy-duty vehicles are projected to add significant amounts of global oil demand by 2040. Better technology, however, could vastly improve the efficiency of U.S. heavy-duty trucks, including through demonstrated technical improvements and retrofits, such as use of the latest digital engines. There are also efficiency gains to be had from efficient driving, permitting two trailers per tractor on highways, intermodal shifts (e.g., from road to rail), and logistical improvements (e.g., the "Uber for freight" model that is emerging in China and India to reduce empty miles by matching loads with trips).

In the United States, there are more than a million heavy-duty trucks on the road, which turn over every few years or so. There are also only a handful of companies in the country that make the trucks. That makes heavy-duty fleets a narrow but impactful decarbonization target.

Batteries may or may not make sense for heavy-duty trucks, depending on how efficient the trucks can be made (and thus how many batteries are needed). For the battery-electric heavy-duty trucks that are being developed so far, electricity demand charges are a particular issue, as they will require significant amounts of charging capacity. Heavy-duty charging is a tough nut to crack. Medium-duty trucks might be a better fit for EVs, but production capabilities for those technologies have generally fallen far short of the demand corporate fleet operators have. As production volumes ramp up, fleet operators will have to make investments and changes in charging infrastructure. Depending on their usage, it is also possible that medium- and heavy-duty EV trucks, buses, and other vehicles could be good candidates for providing bidirectional power services and storage for the electric grid. Beyond batteries, hydrogen fuel cells are another option being explored for decarbonizing medium- and heavy-duty transport.

Moving off-road, the growth of precision agriculture has led to increased interest in electrified, autonomous tractors, which have high upfront costs but significant operational benefits. The challenge is that farms are often at the end of a weak grid, so charging EVs in the agricultural context remains problematic. More broadly, if scaling up of EVs (whether light-duty, heavy-duty, or off-road) occurs, many rural areas and the rural electric co-ops that serve them are not thinking about EVs at all right now and may not be ready to handle the operational and infrastructure changes that will be needed.

PLANES

Traffic and fuel use are growing fastest for airplanes. Planes certified in 2000 versus 1960 cut fuel intensity by 70% (half from better engines, half from better airframes), and key technologies have kept advancing, yielding continued incremental baseline improvements. Today's planes get 20% more efficient each generation. Far greater efficiency gains are possible and cost-effective, however, and changes could be accelerated with golden carrot solicitations from large customers. Design modifications to wings, composite structures, propulsion systems, and other innovations can save 50-80% of fuel use. For example, technology allows flight surfaces to morph in real-time to adapt to conditions, leaving the flight surface smooth, and there are major companies seeking to commercialize that kind of wing-morphing technology today. The most important tactic may be reducing weight by using more carbon-fiber in frames; today's Dreamliner is only half carbon. With regard to engines, experts expect several more decades of 7%-per-decade gains in gas turbines' efficiencies, but some companies have recently 3-D printed fuel nozzles that helped improve engine efficiency 10%.

Finding low- and zero-carbon fuels for aviation will be important. There are fewer than 2,000 major aviation fueling hubs, so if alternative fuels can break into the markets, there is a relatively narrow infrastructure universe to target. At least a few firms are offering batteries that enable short-haul and potentially medium-haul electric planes, and large-area batteries could someday form both the skin and structure of an airplane. For long-haul intercontinental flights, fueling with liquid hydrogen (as rockets do) can raise efficiency gains 5- to 7-fold. Biofuels are another possibility. Within the energy system, modeling suggests that the best use of the limited supply of available biomass may be bio-refineries with CCS (to capture and store the emissions from the production process), as there appears to be more carbon benefit from making fuels (and displacing diesel or jet fuel) than from making electricity. Given how far behind biofuels are, though, some wonder whether it would make more sense to stick with fossil-based liquid fuels and ramp up the amount of DAC used, assuming DAC prices come down enough.

INDUSTRY

Even though industry accounts for about one-third of global emissions, it accounts for a far, far smaller fraction of global effort on decarbonization.

CROSS-CUTTING OPPORTUNITIES

It is important to recognize that "industry" is not monolithic. The scale of individual sources of industry emissions can vary widely, though they tend to be much smaller than the emissions levels of power plants. Different industries also have different energy needs and different options for meeting those needs in a low-carbon way. Still, there are decarbonization focus areas that cut across industrial sectors, such as more efficient motors. Another key cross-cutting solution will likely be industrial CCUS (discussed in more detail in the next section, Carbon Capture & Removal).

Pushing clean electricity into other sectors is seen as one of the key steps of deep decarbonization, and there are opportunities for electrification in the industrial sector.

As discussed earlier, pushing clean electricity into other sectors is seen as one of the key steps of deep decarbonization, and there are opportunities for electrification in the industrial sector as well, such as process electrification. Given the weather-dependent nature of wind and solar power (absent large-scale storage), some wonder whether the industrial process paradigm could be redesigned to work on variable input to take advantage of very low-cost direct renewable electricity.

Zero-carbon hydrogen could also be used to help decarbonize the industrial sector, either as a form of heat or as a reductant or chemical reactant. Cheap hydrogen could change a lot of forecasts and outcomes in many sectors. There is a risk, though, that capital flows and market dynamics may not deploy solutions such as hydrogen in the areas of highest carbon impact. For example, putting hydrogen into the power sector, in competition with several other zero-carbon resources, may not be as impactful in terms of climate change as directing hydrogen use towards blast furnaces and harder-to-decarbonize industrial processes. In addition, some think nuclear plants (e.g., in the form of small modular reactors) could be used for high-temperature process heat.

STEEL, CEMENT, & PLASTICS

Steel is an interesting industry in terms of supply, demand, and decarbonization. Given the projected growth rates in steel usage and the huge amount of existing unused capacity, there may never be a need to build another steel plant again – but the existing ones are very high-emitting. Incorporation of cleaner technologies into a new steel plant therefore has to compete against the shutdown and/or retrofit economics of existing plants. Decarbonization solutions discussed in the steel context generally encompass the ones mentioned above, including CCS, hydrogen, and electrification. For instance, direct reduction of iron is done with methane now, but it could potentially be done with hydrogen if that hydrogen was zero-carbon and cheap. Sweden is now building the first direct-hydrogen-reduction pilot steel plant. There is also the potential to use electrolysis for iron ore, which is a very energy efficient process that could be cost-competitive when electricity is cheap. The precise process control that an electrification approach provides would also improve the quality of the steel, and the higher value of the purer electrolytic steel could potentially tip the economics. Making such high-value products can be one way to expand the use of industrial low-carbon technologies and march them down the experiential cost curve.

Some of the largest steel companies in the world are working together to try to figure out standards to promote cleaner steel. There are companies in Europe looking to do the same with cement.

Cement's carbon footprint comes both from heat and from the CO_2 released by the breakdown of calcium carbonate. The biggest opportunity for decarbonization is likely alternative cement chemistries, and there is lots of innovation happening in that area, though no perfect solution has been found yet. It is likely that different approaches will be needed for different regions, depending on the inputs that are available at cost and at scale. In addition, CCS could again be part of the solution. Electrifying heating for cement, on the other hand, will be difficult, given the high heat levels needed.

Plastics production, which has been booming, is another source of industrial GHG emissions. Ehtylene is the backbone of a lot of plastics production, and it requires a lot of energy and steam to produce. Burning plastics at the end of their lives produces even more emissions, but it is challenging to devise cost-effective recycling of very diverse plastic flows to turn them back into their constituent chemicals for reuse. The most viable solution regarding ethylene may be to take cellulosic or low-GHG ethanol and turn it into ethylene with a catalyst, but that ethanol would have to be far cheaper than it is now. It is possible that an electrolyzer could cost-effectively be used to produce ethylene as well.

DRIVERS FOR LOW-CARBON MATERIALS

Some policy efforts have sought to drive demand for materials made through low-carbon production, such as the Buy Clean California legislation, which includes steel. Much more is needed, however. If those types of government procurement programs expanded in geographic scope and the types of materials covered, they could have a much bigger effect in developing markets for lower-carbon products. If, for example, state and federal transportation departments said they would buy 5% of all their concrete and steel as low-carbon, they are such large buyers that they would create a protected market that could move industries. (On the other hand, particularly at a national level, it is unclear if pushes for Buy American provisions and for Buy Clean provisions would align.) Accounting for the lifecycle greenhouse gas impacts of different materials will be challenging – California is in the weeds of it now – but the accounting measures do not have to be perfect; they just need to be good enough to create a framework for valuing one process or material over another.

Corporate procurement can likewise have a big impact. Materials such as aluminum make up a big part of some tech companies' carbon footprints, and car companies buy a lot of steel. Corporate efforts to decarbonize supply chains could make a difference in those industries.

In general, Europe is several steps ahead of the United States when it comes to addressing industrial emissions. Countries have taken leadership efforts to decarbonize industrial sectors, including France on cement and Sweden and Norway on steel. The Port of Rotterdam in the Netherlands is seeking to be a clean hub for CCS and hydrogen, and the United Kingdom has taken some leadership on CCS. Leakage, though, is an important concern when nations seek to address industrial emissions. China, for instance, has stated its goal of reducing the percentage of its economy devoted to steel, cement, and other energy-intensive products, but if those emissions simply move to Vietnam or some other country, little has actually been gained in terms of climate change.

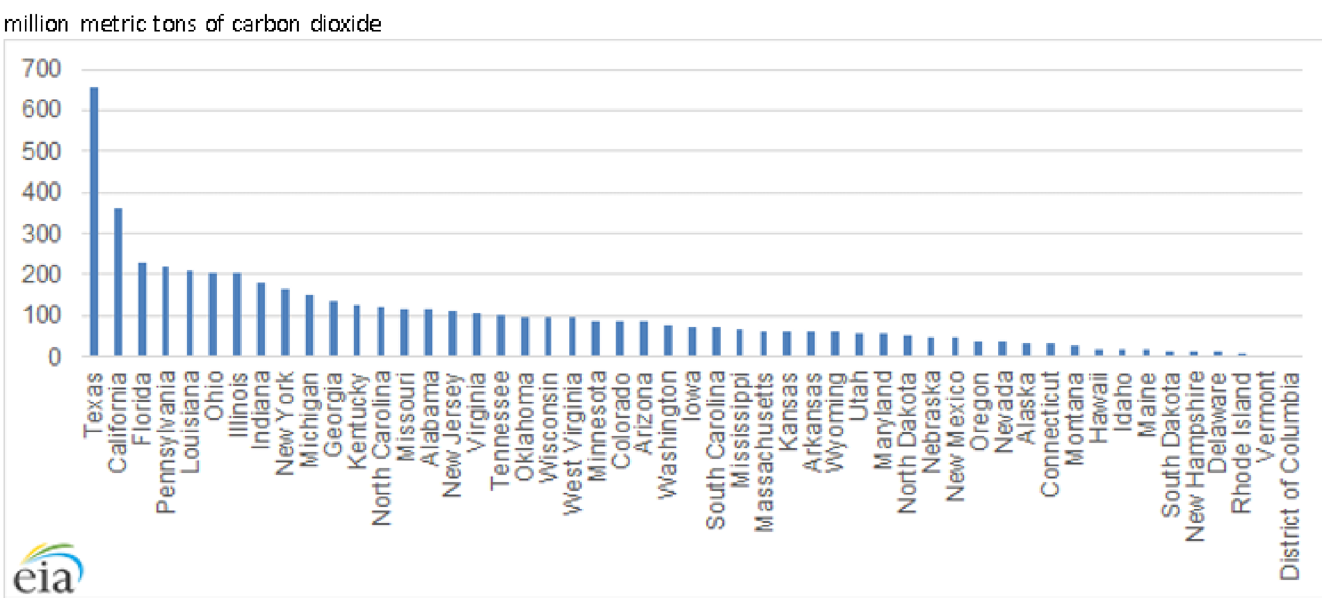
REDUCING DEMAND FOR CARBON-INTENSIVE MATERIALS

The supply side plays a role in reducing industrial emissions, such as through better processes, better chemistries, and cleaner fuels. The demand side, though, cannot be ignored; it is easier to decarbonize if there are lower energy needs and less materials production. There do not appear to be good, systematic efforts, however, to compare the benefits of investing in demand-side solutions versus supply-side solutions.

More efficient equipment and processes are an obvious starting point for reducing industrial energy needs. For instance, with regard to industrial process heat, electric heat pumps have gotten more efficient, while their outputs have been rising. Likewise, fine chemical plants use lots of energy to separate unwanted byproducts, but micro-reactors can control reactions so precisely that there is no waste to separate. In addition, integrative design in all sectors can yield radical energy efficiency – at much lower cost and often with increasing returns – not from adding more widgets but rather from more artfully combining and sequencing fewer and simpler widgets.

There are also opportunities to reduce demand for energy-intensive materials such as cement and steel. For instance, the delivery of services through on-site technologies such as 3-D printing would reduce the need for factories, warehouses, vehicles, and other infrastructure that use a lot of concrete and steel. Likewise, business models that deliver services instead of stuff – such as leasing structural performance instead of selling tons of cement – could reward the best performance with the least material; the concept is taking hold in other industries and could apply to structural materials as well. Improving the uniformity and quality of cement can reduce the amount needed. Reducing, re-using, and recycling construction and demolition waste could allow for valuable reuse of cement in new concrete, and there will soon be enough steel out in the world that effectively recycling the amount coming off as scrap could meet the amount of steel needed every year. Frugal structural design, too, can vastly reduce the need for energy-intensive materials, such as by substituting tension for compression structures and utilizing fabric forms. There are also lots of mass-efficient designs and materials in nature that can be imitated. Furthermore, steel and concrete can be replaced

Figure 1. Energy-related carbon dioxide emissions by state, 2016



Source: EIA, State Energy Data System and EIA calculations made for this analysis.

Figure 1: Source: Rhodium Group's US Climate Service

in some uses with less carbon-intensive materials such as bamboo, wood, and carbon fiber; revising building standards so that they are based on the performance needed and not on particular types and amounts of materials could open up markets for substitute materials.

THE GULF COAST

Those looking to reduce industrial emissions in the United States are basically talking about Texas, which is – currently and in the projected future – the largest industrial emitter in the country by far. Texas has more emissions from chemicals and refining than the rest of the United States put together (not to mention the emissions from upstream oil and gas production). Texas and Louisiana together – the #1 and #2 state emitters – account for the vast majority of U.S. industrial greenhouse gas emissions.

Billions of dollars are also being spent in the Gulf Coast on new petrochemical expansions and refining. These are facilities and infrastructure with long, multi-decadal lifespans, and if this buildout goes forward at the scale planned without GHG controls, the climate problem will be much more difficult to address. Some wonder whether the United States – Texas and Louisiana, in particular – needs some kind of industrial policy to rationalize development while addressing climate change. There are questions that need to be addressed, such as who pays for the needed CCS, whether tougher regulations are needed for new petrochemical infrastructure, and how hydrogen will grow its market share while cheap natural gas keeps getting pumped out of the Permian.

CARBON CAPTURE & REMOVAL

Across sectors, there will almost certainly still be lots of carbon-based energy for years to come. Carbon capture, utilization, and storage technologies will affect the ability of fossil fuels to participate in a deeply decarbonized world, while carbon dioxide removal technologies could prove vital to keeping atmospheric GHG concentrations within agreed-upon bounds.

Carbon capture, utilization, and storage technologies will affect the ability of fossil fuels to participate in a deeply decarbonized world.

CARBON CAPTURE

As noted earlier in this report, carbon capture can be a potential decarbonization solution in both the power and industrial sectors. In the power sector, the Kemper plant in Mississippi is often put forth as a high-profile failure of CCS application, but Petra Nova in Texas may be a more instructive example of a successful post-combustion retrofit project. Also attracting a great deal of attention is the NET Power demonstration plant in Texas, which is designed to take natural gas, produce electricity, and capture all the CO_2 – all at a competitive price.

NET Power can be used flexibly to produce heat or electricity, while also producing streams of CO_2, nitrogen, and argon. This means the technology could have decarbonization potential across sectors, as well as multiple potential income streams. It could produce steam to drive hydrogen production, combine its nitrogen stream with hydrogen to make ammonia (for use in agriculture or as a carrier for hydrogen), purify sour gas cheaply for use in the hydrogen process, and/or direct its captured CO_2 for use in enhanced oil recovery or for use as a feedstock.

In the industrial sector, carbon dioxide emissions are complicated, with different streams and CO_2 concentrations often occurring in the same unit; depending on the industry, there could be 3-10 streams of CO_2 generated. There is a question, then, as to whether it is more desirable to have carbon capture technology on each stream or to combine the streams (which could dilute the CO_2 concentrations) and have only one capture unit. The potential low-cost capture solutions can vary by industry. For instance, oxycombustion with chemical looping could be a good, cost-effective solution for cement production within about a decade, and investments in oxycombustion could have applications in other industrial sectors as well. Advanced solvents, membranes, and solid sorbents could also play roles across sectors, including in iron and steel, which has a complex mix of emission sources. Membranes are low-cost and modular and might work in units where chemical reactions occur. Sorbents, meanwhile, require relatively low temperatures for regeneration, which could be met by the waste heat that already exists in many industrial processes.

Commercial demand for CCS technologies exists, but there are a small number of entities that like to be among the first customers. There are many more ready to be in the next wave. The federal 45Q tax credit for CCUS can help the economics of these technologies, and most of the top industry emitters qualify for the credit. The fact that the 45Q credit is currently scheduled to expire in 2023 – so there is a finite window of opportunity – will likely drive a lot of demand.

CARBON REMOVAL

Many deep decarbonization scenarios to limit warming to 2°C involve some removal of carbon dioxide from the atmosphere, and even more do if the goal is 1.5°C. CDR solutions can both offset emissions from difficult sectors and protect against overshooting climate targets if humanity continues to delay serious action on climate change. Negative emissions technologies are likely vital to deep decarbonization of the U.S. energy system, though the extent of the need for NETs will depend on how many other solutions are available. Estimates vary regarding how much additional carbon removal is needed, but they are generally somewhere around 10 Gt of CO_2 per year by 2050. That is equivalent to about one-quarter of global emissions today. It is not a small number, and there is very little additional carbon removal happening now. The few existing DAC plants, for instance, are removing on the order of single-digit kilotons of CO_2 per year.

There are a lot of potential solutions in the carbon dioxide removal toolbox. There are biological, land-based approaches, which involve storing carbon in forests, soils, and ecosystems. There are approaches such as enhanced weathering, to increase mineralization of CO_2. There are also engineered approaches that use chemical processes, such as DAC. Not everyone sees the need for engineered carbon removal solutions, arguing that biological systems could do the job at lower cost, but each solution has its drawbacks and limitations. A National Academy of Sciences study on removal indicated that about 6 Gt per year could come from the land sector under $100/ton, which is substantial but still short of the need. The land sector is also at risk of becoming a carbon source instead of a sink as climate impacts increase. On the engineering side, bioenergy with carbon capture and storage (BECCS) is limited by the availability of land and biomass. DAC is limited by high costs and access to clean energy. Given the shortcomings of each individual solution, a portfolio approach to removal appears to be advisable.

Direct air capture has received increased attention recently, particularly following the launch of a few DAC plants in Europe. As just noted, DAC is limited by high costs. The costs of DAC systems using sorbents are dominated by the sorbents, whereas the costs of systems using solvents are dominated by equipment. Whether using solvents or sorbents, the vast majority of the energy associated with DAC is thermal energy for regeneration, with the remaining being electric load for pumps, fans, and the like. Solid sorbents require lower levels of heat (around 100°C) for regeneration than liquid solvents (around 900°C), and their modularity could enable standardized manufacturing. The cost of solid sorbents is very high, though.

There are existing sources of low-temperature, low-carbon heat adequate for DAC with sorbents, and piggybacking on existing systems could reduce the levels of needed infrastructure investment. For instance, in geothermal power plants, the working fluid that is used for the turbines could be intercepted at the end, run through a DAC plant, and then reinjected back into the earth just as geothermal plants regularly do (as long as heat exchangers are used so the sorbent never touches and contaminates the fluid). In nuclear power plants, the waste heat is at too low a temperature, so the heat would have to be intercepted earlier in the system, such as by taking a small amount of steam away from producing electricity (the costs for which would have to be accounted for in figuring the costs of the DAC system). Stranded natural gas (i.e., flared gas) could be another source for heat. While that kind of arrangement would avoid emissions from flaring, the emissions from combusting the gas would have to be captured. Also, unlike nuclear and geothermal plants, there would be no infrastructure on which to piggyback, so a DAC system would have to create the infrastructure for making steam.

There is a lot of waste heat in industry as well. A 2016 Department of Energy study found that there are 50,000 industry-based combined heat and power (CHP) sites in the United States, as well as another 240,000 commercial-based CHP sites. Doing DAC at these sites would result in 740 Mt CO_2 per year removed from the atmosphere.

The more infrastructure that needs to be built, the higher the costs for the DAC system will be. Likewise, the more embedded emissions there are in DAC plant materials such as steel and concrete, and the higher the carbon intensity of the local grid that powers the plant, the higher the plant's cost of net CO_2 removed will be.

Getting DAC and other CDR technologies to the necessary scale will be challenging. Some technologies could be deployed now, while others are still in the lab. Many are primed for investment by governments, corporations, and philanthropists. These removal technologies need to be accelerated in ways similar to what led solar to experience plunging costs and increasing competitiveness. A lot of the growth in solar PV was due to government incentives, as well as technological advancements, and both may be needed to enable DAC and other CDR technologies to increase deployment now so they can move along similar experience, learning, and cost-reduction curves to the point that they can eventually be deployed at large, net-negative scale. There are initial policy opportunities from the 45Q tax credit, as well as from the California Low-Carbon Fuel Standard (LCFS), which currently pays $190/ton for DAC anywhere in the world that is followed by geologic storage – under the rationale that it is basically post-combustion capture for cars.

It is worth being cognizant of the possibility that CDR technologies could have political and geopolitical implications. For instance, if the rest of the world has CDR opportunities that are less costly than the United States doing DAC, it might be more cost-effective for the United States to spend money on, say, forest protection/growth in other countries than on DAC for its own emissions. It is unclear, though, if that would pass muster politically. Relying on offsets outside U.S. borders will be criticized for outsourcing the hard work, as well as for potentially sacrificing domestic industrial opportunities. On the other hand, if the United States manages to eventually eliminate its own emissions, but the goal is to get to global net negative, then the United States could be running DAC that pulls out the emissions of other countries that are still emitting. That could be seen as unpaid charity work for the rest of the world, though others would characterize it as rebalancing the historical U.S. contributions to the problem.

CARBON UTILIZATION & STORAGE

Once carbon dioxide has been captured from industrial or power processes or from the air, something has to be done with it. There are generally two main options: use it for something or bury it.

Captured carbon dioxide can be used as a feedstock in making products such as plastics and nanofibers, which keep the carbon sequestered in them, as well as to make fuels. Some DAC plants have also signed contracts with beverage makers to provide CO_2 for carbonated water. The price range for CO_2 in the beverage industry is between $300 and $1000/ton for smaller operators. (At the super-small level, like Sodastreams in people's homes, the cost for CO_2 works out to around $40,000/ton.) Consumers clearly will pay for CO_2. It is possible some brewers or beverage makers would also be excited to have CO_2 from DAC for marketing purposes – something akin to the organic label ("clean cola"?) – but businesses so far have not found that consumers are willing to pay a premium for products with climate benefits (unlike products that are seen as having health benefits). There is also a need to create some kind of certification program for carbon-free products created via CCUS, to help buyers have confidence. Still, there are valuable markets to be found here; the total potential market size for "carbontech" is estimated to be around $1 trillion in the United States and $6 trillion globally. The relatively tiny amounts of CO_2 used by the beverage industry (around 3 million tons per year) and by some of the other early markets for carbon utilization will not impact the climate much, but there is money to be made, and such deals for beneficial reuse can serve as a starting point for helping deploy plants, advance learning-by-doing, get costs down, and achieve scale. At this stage in the game, it almost does not matter what the particular uses of CCUS, DAC, and other carbon capture and removal technologies are – as long as more projects are getting built so that progress can be made down the cost and experience curves.

To advance carbon utilization, pipelines to transport streams of CO_2 from where they are produced to where they can be utilized are needed. There may be a need for government to take on some of the long-term risks, as private equity cannot usually handle the length of time it takes to fill the list of a pipeline's buyers.

Pipelines will also be needed to transport CO_2 to sequestration sites. To achieve climate targets, the United States will need to get really good at putting CO_2 in the ground, at levels that are orders of magnitude higher than today. The United States has plenty of geological storage capacity, so the issue is more about expertise, infrastructure, public acceptance, and economics. The 45Q tax credit can help with the economics, and there are opportunities to minimize needed infrastructure by identifying locations that have both good geologic sinks and existing low-temperature, low-carbon waste heat sources adequate for DAC. Honest discussions are needed around CO_2 pipelines and sequestration, though, to help the public and other stakeholders understand the true risks, as well as the potential mitigation options for those risks. There is likewise a need for transparency around claims that what is geologically stored will stay there, so the public can understand and accept the validity of carbon sequestration.

Enhanced oil recovery (EOR) is a combination of the two options for CO_2, involving both beneficial utilization and storage. EOR is not new; it has been done for decades without major issues. Injected CO_2 mixes with oil, displaces some in pore spaces, and makes oil flow more easily. Some of the injected CO_2 stays underground (and helps maintain pressure in the fields); it is a form of geologic sequestration. Currently, EOR in the United States uses around 70 million tons of CO_2 per year, most of which is from natural sources. The cost of this CO_2 is tied to the price of oil, and producers pay around $30/ton. There are lots of industry sources of CO_2 that could be used instead of natural sources, though, thereby sequestering anthropogenic emissions. There are ways to do such EOR that would pay the operator for keeping CO_2 in the earth (e.g., through the 45Q tax credit) and that could optimize both oil production and CO_2 sequestration. Oil produced using anthropogenic CO_2 has a much lower carbon footprint than a conventionally produced barrel of oil and could displace really carbon-intensive oil (e.g., from oil sands). There is an opportunity there – though it is not clear how big – to help decarbonize transport, and California has included such oil in its LCFS. Similarly, unconventional shale can absorb a lot of CO_2, and there is an opportunity to use it as a fracking agent.

POLICIES & POLITICS

Climate change is a social, economic, environmental, jobs, and ethical issue – and policy matters tremendously. There is a need for new, broader, smarter, more significant policy approaches to address the climate challenge. Fortunately, in both state and federal policy circles, climate change is receiving political attention that it has not had for years.

POLICY OPTIONS & CONSIDERATIONS

Emissions pricing is portrayed by some as an idealized policy. GHG emissions impose costs on society, and if those costs are not somehow reflected in decision-making, then they will remain externalities. An emissions price could provide a clear economic signal. Yet carbon pricing policies appear to be difficult to enact in the United States. To the extent that an economy-wide carbon price can make it through the political gauntlets, whatever comes out of the policymaking process almost certainly will not be elegant and simple, but rather riddled with compromises. It is also essential to recognize that emissions pricing cannot address all the issues involved in having an efficient and effective path to deep decarbonization.

Zero-carbon fuels, for instance, are still largely an innovation game requiring significant investment. CCUS and CDR technologies are likewise an innovation game, with a focus both on creating new technologies and on driving costs down and deployment up for existing technologies. Broadly speaking, governmental policies are not always needed or of help in promoting technological innovation and deployment. Some technologies are profitable and attractive without any government help. Sometimes, policies create impediments to widespread market adoption of the best technologies, and other times policies can be both a lever and a hurdle to deploying the best technologies. For example, minimum efficiency standards for HVAC systems have had a huge impact in levering the industry up to a set floor but have also led to the market being dominated by HVAC technologies that are at that minimum level, hindering the growth of better, more efficient, and more productive technologies. However, technologies sometimes require government help to advance innovation and reach scale, and zero-carbon fuels, CCUS, and CDR may fall in that category. Innovations are generally hard for any individual company to capture the full value of, so there is a need for a range of RD&D policy approaches, including public funding, tax incentives for private effort, and government procurement.

Labeling, certification, and performance measurement policies and protocols are another important set of policy options, as information is critical to making sound decisions. These types of measures, for instance, can help potential large corporate buyers figure out what qualifies as "clean" energy. International certification bodies can be a way to drive policy and action across borders.

Network- and systems-level effects have to be considered as well, especially where there are large fixed costs associated with infrastructure and systems. Systems thinking – how to take a collection of equipment and put them together in a way that optimizes the whole – represents an untapped well of potential energy savings, and advanced machine learning and artificial intelligence could be big drivers of it. Infrastructure policies, such as those related to EV charging networks and building codes, can therefore matter a lot. Likewise, for systems to work, particularly ones made up of technologies made by different manufacturers, interoperability standards will be vital (e.g., for behind-the-meter devices), but policies for those systems also must pay significant attention to cybersecurity, privacy, data ownership, and resilience concerns.

Equity has to be part of the climate policy conversation too, in terms of both access to clean energy and support to deal with the effects of climate change and the clean energy transition.

Geographic spillovers also have to be considered. Depending on the scope of a policy and the jurisdiction enacting it, there could be interactions with other jurisdictions that have to be kept in mind, leading to policy mechanisms such as carbon border adjustments.

Equity has to be part of the climate policy conversation too, in terms of both access to clean energy and support to deal with the effects of climate change and the clean energy transition. Dealing with traditional disadvantaged communities and with coal communities are different problems with different solutions, but both are important moral questions of environmental and economic justice and are important to long-term political success. More deep thinking is needed about the impacts of existing technologies on disadvantaged communities and of a clean energy transition on coal communities.

The challenge is not just to design energy and climate policies to meet science-based targets, but also to grapple with the significant human, community, and social values that are at stake. Many of the states most affected by climate change impacts are red states, and efforts to address resilience and stranded assets, workers, and communities can help bridge the right-left and rural-urban divides. Talk about "green jobs" and "just transition" has started to ring hollow to some communities that expected job booms and then faced a crash once the initial construction jobs went away; there is a need to get serious about job recruitment, development, and training and to think about what it takes to create real career opportunities. Climate policy cannot just involve pulling wealth out of the middle states and sending it to the coasts. Rural electric co-ops can be a testbed for addressing some of the key equity issues and policies related to climate change and a clean energy transition, as they are in most Congressional districts and cover the vast majority of counties with persistent poverty. In addition, states such as California are increasingly looking at how to marry climate policy and social equity through legislation that links climate targets with social equity imperatives and requirements.

SECTORAL POLICY APPROACHES

An additional way of considering policy options is to look at sectoral approaches, particularly through the lens of the policy drivers needed for each of the various steps of deep decarbonization – energy efficiency, decarbonized electricity, electrification of other sectors, zero-carbon fuels, and CCUS and CDR. Economy-wide carbon pricing could spur changes in some sectors, but it may not move the needle much in others, so there will be a need to go sector by sector to identify barriers. Energy efficiency and many decarbonized electricity solutions can be fostered and deployed quickly, whereas solutions in some other sectors (e.g., industrial, agricultural) may need more time. Electrification of other sectors is also of less benefit if the electricity mix has not yet been cleaned up. Getting ahead in the "easier" sectors can create room to act later in other areas, though near-term policy actions will still be needed to develop the ability to act at scale in the "harder" sectors. Fit-for-purpose policy solutions should be devised for different sectors.

The policies in the power sector are in some ways the clearest, involving measures such as energy efficiency standards, RPSs, clean energy standards (CESs), and cap-and-trade. Many of these policies can be used not just for efficiency and renewables but also to drive other critical zero-carbon dispatchable resources such as nuclear, hydro, and hydrogen. For instance, properly designed CESs can help retain existing zero-carbon generation and can achieve most of the benefits of a carbon price in the power sector. A CES could also be designed to be symmetric, giving negative credits to higher emitters. Technologies such as long-term storage may require additional policy support, such as by creating carve-outs tied to duration in state policies and mandates for storage (which currently tend to involve pursuing least-cost options but specify nothing about duration).

It is less clear what the state or federal policies should be to electrify other sectors. Some could involve small but meaningful changes in electricity regulations. For instance, as the grid gets cleaner and other sectors get electrified, it might make sense to transition from energy efficiency standards and energy savings targets to carbon efficiency standards (while still recognizing that energy efficiency and energy savings efforts in other sectors can make electrification easier by leaving less energy load to electrify). Electrifying other sectors will increase electricity usage, but if clean electricity displaces, say, oil in the transportation sector, then carbon intensity would go down. The issue becomes less about using fewer electrons and more about using less carbon, so carbon may need to start becoming the underlying metric.

The challenge is not just to design energy and climate policies to meet science-based targets, but also to grapple with the significant human, community, and social values that are at stake.

It is not clear that a carbon price – at least one likely to make it through the political process – would meaningfully change behavior in transportation or the makeup of the vehicle fleet. For instance, a $25/ton carbon price translates to an increase of only about $0.25 for a gallon of gasoline. This is one of the reasons that performance standards such as greenhouse gas and fuel economy standards for vehicles are such an important policy lever. If those standards ramp up enough, it will get to the point that vehicle manufacturers that currently have mixed fleets will switch more production to EVs. At the moment, however, federal efforts related to fuel economy standards are moving in the opposite direction. Low-carbon fuel standards are another performance standard that could promote zero-carbon fuels and electrification of transport. Some wonder, though, whether some kind of broader U.S. industrial policy is needed to drive EVs. While EVs are beginning to take off in the United States, with a couple of models having reached some kind of scale, China and India both see EVs as part of their industrial policies and are specifically promoting them. China, for instance, has more than a dozen EV models already at scale, and the Shenzhen region has huge numbers of electric buses, taxis, and urban delivery and service vehicles. The United States has no comparable industrial policy or similar ecosystem to drive such development.

Building codes are another key policy avenue. They generally operate at the state or local level and can help drive electrification of both buildings (directly) and transport (e.g., by requiring charging infrastructure).

In industry, some studies suggest a carbon price would have minimal impacts on emissions. A substantial carbon price (far higher than is likely to make it through the political process) would almost certainly cause sizable increases in the costs of carbon-intensive materials such as steel, cement, and ethylene, but the change in final costs to consumers of finished products (e.g., cars, bridges, bottled soft drinks) would be fairly negligible. Carbon pricing policies would thus have minimal impact on consumers, but they make producers very nervous. There are other good policy levers, though, such as government procurement (e.g., Buy Clean) policies that can create protected markets for low-carbon cement, steel, and other materials. Infrastructure policies that can advance CCUS, such as by facilitating development of CO2 pipelines, could also be of significant benefit.

In the agricultural sector, policies and programs can help farmers increase soil carbon sequestration, which at the same time will boost soil quality and improve crops. Policies to facilitate use of portions of farmland for renewables can help farmers receive lease payments that can offset commodity price variability and be the difference between a family farm surviving or not. Policies to clarify the treatment and uses of biomass and biogas for decarbonization could have similar effects. Such efforts can also foster examples of economic vitality in rural America, reframe the conversation around climate change, and build political support for climate action from the ground up. It can be complex, though, to navigate between policies and programs available from the Department of Agriculture, the Department of Energy, states, and others.

There likely will not be one big policy idea that drives decarbonization so much as a mosaic of approaches.

As the above examples make clear, there likely will not be one big policy idea that drives decarbonization so much as a mosaic of approaches, sometimes targeted at specific sectors and sometimes cutting across sectors. There is a need to be humble about policy experimentation and learning by doing, as well as to advance public-private and private-civil society partnerships in areas where they may be more effective than policy.

STATE POLICY DEVELOPMENTS

States are hugely significant drivers of energy and climate policies, and the 2018 election had notable consequences at the state level in this regard. There were, for instance, several clean energy measures on state ballots, including ones that got withdrawn in Michigan (because the utilities adopted GHG reduction goals), defeated in Arizona, and adopted in Nevada. A high-profile carbon fee ballot initiative was defeated in Washington for the second cycle in a row. The Washington ballot measure failed for a range of reasons, including that none of the key industries that would be significantly impacted by the measure (e.g., energy, industrial, agriculture) were engaged in supporting it, the measure tried to do too many things at the same time from the same pot of money, and ballot measure supporters got outspent 2-1 by the fossil fuel industry (and it would have been 3-1 if it had needed to be).

The past couple of years have also seen some important changes in governorships. In the 2017 election cycle, new governors came in to New Jersey and Virginia with much clearer focuses on clean energy and climate change. In the 2018 cycle, Democrats who campaigned in part on climate and clean energy issues won several races to replace Republican governors, some of whom had also been strong on clean energy and some of whom had stood in the way of clean energy progress. Not every election went that way, as in Florida, but even there, it is possible that the new Republican governor might be creating some openings for a clean energy policy discussion that were not present under the prior governor. Activity on these issues has generally been far more bipartisan at the state level than at the federal, as many state legislators and governors of both parties are looking at how to move forward.

Several states have adopted or are in the process of considering their clean energy goals. California passed a CES in 2018 as part of raising its renewable energy standard, and other states are looking at the idea. Hawaii has doubled down on its 100% renewable energy goal, but so far it remains the only state to adopt one (though Washington, DC did as well). In Colorado, the new governor, who campaigned on a 100% renewable energy goal, is not a fan of top-down mandates and is looking at other tools, such as requiring carbon pricing in utility resource planning.

In addition, even with the Clean Power Plan stayed, the vast majority of the coal plants in the West that existed in 2017 will be gone in 2035 – due to resource planning, the age of the plants, the cost of replacement, the declining cost of renewables, and cheap natural gas – leading many Western states to actively ponder what the transition will look like. Both Colorado and New Mexico, for instance, are looking at securitization for coal retirements. Likewise, in Canada, Alberta's government set up a mechanism for transition payments for producers' stranded coal assets, as well as to help impacted communities.

States are also doing active work on carbon policy. California renewed its cap-and-trade program, and Oregon is debating a legislative cap-and-trade policy. Several Northeast and Mid-Atlantic states also signed on to the Transportation and Climate Initiative to decarbonize transportation, and many states are exploring whether and how utilities can own infrastructure to advance zero-emission vehicles. At the same time, even while looking at stronger carbon goals, many states are also seeing rapid buildout of new gas, which could make achievement of those goals more difficult.

There is a lot happening at the state level, much of it driven by the federal vacuum on clean energy and carbon policy. There are opportunities in states to develop some model policies that could be used to build coalitions that could eventually be brought to bear on national policy. The clean energy and climate policy developments at the state level could also open some eyes in DC, and the greater the diversity of local, state, regional, and regulatory measures on carbon, the more a federal legislative solution will be seen as a way to clean up and reconcile a bunch of ad hoc, sometimes conflicting measures. An issue on the table in federal policy discussions, then, is whether federal policy will help and complement state action or seek to override or suppress it.

CHANGING FEDERAL DYNAMICS

The 2018 elections had an impact on the dynamics of the federal climate policy discussion as well. Democrats took control of the House of Representatives, and some of them ran on strong climate and clean energy policy platforms. Rep. Carlos Curbelo of Florida and some other climate-focused moderate Republicans lost their races, though many of those were very junior members of Congress and most (Curbelo excepted) were not on relevant committees of jurisdiction. The people that matter far more to clean energy and climate progress are the people on the committees. Sen. John Barrasso (R-WY), for instance, who is the chairman of the Senate Committee on Environment and Public Works and who also sits on the Energy and Natural Resources Committee, will be involved in these issues for a decade and may be the key to getting some kind of climate or clean energy policy through the Senate.

There are opportunities in states to develop some model policies that could be used to build coalitions that could eventually be brought to bear on national policy.

Post-election, the Green New Deal has dominated the climate narrative in Congress. The resolution presents a 10-year mobilization plan, essentially laying out an industrial policy to address climate change. There is one section about climate change and the projects that need to happen in the next 10 years, such as enhancing resilience, upgrading infrastructure, getting to 100% carbon-free power, upgrading the energy efficiency of all buildings, and decarbonizing agriculture and industry as much as is technologically feasible. It does not foreclose the use of market mechanisms (e.g., a carbon tax) or any particular technologies (e.g., nuclear, CCUS, CDR). There is also another section with associated goals, such as education for all, guaranteed jobs with benefits, stronger unions, and housing and healthcare – which are not explicitly about climate change but are relevant to supporting a broad economic transition. The Green New Deal thus reframes climate change as a jobs, economic development, health, infrastructure, and justice issue and has broadened the Hill conversation about what else needs to be considered in climate policy. These other issues, along with clean energy, are also very appealing to younger voters. It is important to recognize, though, that the Green New Deal is not a set of policies so much as a statement of goals, which leaves lots of questions about how to actually implement those efforts, who pays, what the role of the private sector is, which technologies to use, and much, much more.

At least partially in response, the tenor of the climate conversation on the right has changed, including among some of the relevant congressional ranking members. Every Republican on the House Energy & Commerce Committee made opening remarks at a recent hearing about the reality of climate change, the need to pivot to solutions, and their view that Republicans had superior solutions from a global perspective; some Republican leaders issued an op-ed along those lines as well. The solutions put forth by Republicans largely relate to innovation, which is undoubtedly a big part of tackling climate change, though it can also be used as an excuse for inaction. While there will be debates over how, how far, how fast, and at what cost, this shift on the right opens up the potential for progress.

In the first few months of 2019 there has been a remarkable evolution towards a more bipartisan climate policy conversation. It is possible that after a decade of camouflaging carbon policy, the time has come to explicitly talk about it. There are still divisions within each party, though. While there are Republican policymakers who are taking decarbonization and accelerated deployment of clean energy seriously, there are still others engaged in the debate of whether climate change is really happening and how much of it is human-caused. In addition, over the last couple of years, on energy issues, there have been parts of the Republican Party that have migrated away from market mechanisms, exhibited a lack of trust in corporate intentions, and favored government interventions. This was seen, for instance, in the DOE NOPR debate. Democrats are mirroring that split, with some members showing mistrust of market mechanisms and corporate intentions and pivoting toward government interventions, as can be seen in some of the Green New Deal messaging. This split on the left is not new; the last time climate change was actively discussed in the federal political sphere, far left groups were throwing political grenades against the Waxman-Markey cap-and-trade bill, accusing its supporters of promoting corporate handouts. That is likely to happen again this time around, although addressing some of the environmental, economic, and social justice issues could help pull in some support from the far left.

There is now an opportunity to work on climate policy at the federal level in a way that there was not before, but this moment of opportunity is clearly fragile. Pressure is needed on both the right and the left to find common ground and advance solutions. It is important, for instance, to figure out how to reward Republican action – to ensure that Republicans become reliable champions for climate action and do not just backtrack to their corners whenever a Democrat is next in the White House. Interested members of Congress need to be educated and supported now, so they can take ownership over policy ideas and buy into them over the long run.

Private-sector, executive-level engagement directly with members of Congress will be important to bring both Republicans and Democrats into the middle, and 2019 has seen a rapid evolution in that regard too. Heavy energy industries have changed how they talk about the issue, with companies issuing significant carbon reduction goals, linking executive compensation to those goals, joining the Oil and Gas Climate Initiative, and advancing conversations about carbon-reducing technologies. In January 2019, the American Petroleum Institute (API) significantly repositioned on climate change, recognizing that it is real and caused by global industrial activity and asserting that the oil and gas industry will lead on solutions – and API can bring along a lot of the center-right caucus in Congress. Trade-exposed industries, including oil and gas companies, may be aligned in interest for the first time toward getting a predictable carbon policy in place. In addition, Wall Street, which has bet big on renewables, has to make the business case for that bet clear to Republican lawmakers; otherwise, the simplistic narrative of the right supporting fossil energy and the left supporting clean energy will persist. More broadly, corporations have to play a bigger role in DC climate politics, which has historically pitted high-energy industries against NGOs. The renewable energy industry, even if it is growing, is still very weak and outgunned politically. Tech companies and others that are working internally to green their operations and supply chains have to get more involved. Private-sector engagement can build a sense of inevitability around a decarbonization transition, and private-sector actions and commitments do matter to members of Congress.

Some believe Congress is currently in the bubbling-up phase of the next round of energy legislation. There was a time, not too many years ago, when energy and climate issues were more regional than partisan, when deals were struck, and when energy policy was boring. The 45Q tax credit is a great example of what can happen when climate policy is not headline-grabbing, and it is worth thinking about other ways of making climate and clean energy policy progress without making a big deal of it. Bipartisan federal legislation usually takes years to germinate – for ideas to be discussed, goals to be narrowed, and reasonable common ground to be found. Getting to 60 votes (or higher) in the Senate likely will not happen by adding additional issues in to create a coalition of the left. The Green New Deal might be good fodder for the Democratic presidential primary, but for legislative action, anything that gets through the Senate will involve expanding the coalition to include the center-right, which will happen through a focus on innovation, competitiveness, and empowering consumers.

Climate advocates need to flood the zone, putting lots of different policy solutions on the table, including market mechanisms, standards, investments, tax credits, and more. They need to fill the void so the DC debate does not just descend into an extreme food fight. Eight years ago, there was only one thing to discuss – the cap-and-trade bill – and so climate action became a binary choice, which led to failure. Flooding the zone creates lots of choices, and there may be some policies Republicans and Democrats can both land on, which could lead to a suite of policies getting adopted in a couple of years.

FEDERAL POLICY DEVELOPMENTS

Comprehensive climate policy is not likely to be adopted in this Congress or under this Administration. Getting "optimal" policies adopted would be great, but in the meantime, sub-optimal policies that better fit the political economy of the moment should be advanced wherever possible. There is no time to wait for the perfect, and it is not a viable option to wait for future elections to press for "home run" climate policies. Things need to happen before then – whether adopting near-term measures that provide climate value or building a broader political foundation for future action. It has to be enough to move faster in the right direction, take opportunities to hit some singles and doubles, and tee up policies and ideas so they are a bigger part of the conversation going forward and will be ready when a political opening arises at the federal level. In politics, a policy can go from "impossible" to "inevitable" without ever passing through "possible".

There are foundations to build on. In many ways, 2018 was a remarkable year for federal clean energy policy. The last Congress enacted the largest increases in clean energy R&D funding in history, enacted significant new tax incentives for CCUS and advanced nuclear (45Q and 45J), implemented regulatory reforms to help advanced nuclear, and authorized new shared research facilities in the Department of Energy. Every single one of these passed in a bipartisan manner. The CCUS measures, for instance, had support from climate champions (for the emission reductions) and from those who do not think climate change is a problem (for the support for continued use of fossil fuels). To be fair, there is a big difference between the dollars appropriated by Congress to DOE and the dollars that DOE actually spent; a lot of the appropriated dollars have never been spent, and some of those that have been spent were spent contrary to congressional direction. (This has apparently been an endemic problem at DOE across administrations; it is a money-spending machine that lacks clear goals or a common direction on what it is trying to accomplish.) Still, the actions in the last Congress prove that things can get done, even in difficult political circumstances.

There are many opportunities in the current Congress to achieve policy wins. Support for innovation is one area with potential for bipartisanship, and there are opportunities to build on the earlier wins in appropriations, though there is a less generous budget cap to deal with this year. There are also active pieces of legislation to further R&D on advanced nuclear and fossil energy. For instance, a big bill in Congress is the reauthorization of DOE's Office of Fossil Energy. Currently, all carbon capture R&D at DOE is under the coal program, but the reauthorization bill under development could make it into a general power sector program. The bill could also add a dedicated industrial carbon capture program and could establish the first-ever dedicated carbon removal R&D program. Indeed, there is an enormous opportunity to enact carbon capture and removal policies in this Congress, with broad, expanded coalitions. In addition, some bills have aimed to give DOE clearer goals, such as demonstrating advanced nuclear reactors within a decade or doing something similar on long-duration grid-scale storage. Some in Congress may be looking at overhauling DOE's Office of Energy Efficiency and Renewable Energy as well, to better advance those technologies.

Infrastructure could be another place to find bipartisan common ground, including enhancing resilience and facilitating pipelines and other infrastructure that can enable scale-up of CCUS and CDR. The USE IT Act, for instance, is a bipartisan, bicameral bill with an R&D title for carbon utilization and DAC and a second title with a set of recommendations regarding infrastructure needs (including pipelines) for broad deployment of carbon capture and removal. This second title addresses things such as the need for more studies and multi-agency coordination.

There are numerous other ideas floating around Congress as well. On the tax front, there are proposals to reform tax incentives to create permanent tax credits for all clean tech based on performance in the market, as well as bills to extend existing tax credits. There are ideas for a federal CES, including one proposal that would achieve 80% lower electricity sector emissions by 2032, with targets automatically accelerating as technologies mature and costs fall, building to 100%. Some Democrats are still interested in resurrecting a cap-and-trade approach, seeking to learn from the fate of the Waxman-Markey effort. A range of other carbon pricing proposals have also been introduced in this Congress and the last, including bipartisan cap-and-dividend bills. These carbon pricing proposals vary in terms of starting price, rate of price rise, effect on EPA Clean Air Act authority to regulate GHG emissions, effect on state programs, and effect on climate-related tort litigation against companies.

Some outside of Congress have raised other ideas. For instance, some advocate for taking the 45Q tax credit, which was passed with bipartisan support, and expanding it to cover more than just CCUS – as a way of getting a bipartisan carbon price adopted without calling it a carbon price. Others have raised the idea of creating a structure similar to the Paris Agreement for U.S. states, with states putting forth their own proposals and wealthier states doing and paying more – which is basically how European climate policy worked. To a degree, though, this is already what is happening, with states such as California and New York leading the way.

Clearly, there is no shortage of policy ideas and activity. The key is to figure out the social and political alchemy that puts policy and technological solutions together in a way that gets broad enough support, creates a coherent and effective enough set of actions and capital deployment, and achieves enough progress in reducing GHG emissions.

APPENDICES: AGENDA

CLEAN ELECTRICITY TRACK: GETTING TO ZERO

MONDAY, FEBRUARY 25

Opening Session

Introduction — **Greg Gershuny**, Interim Director, Energy & Environment Program, The Aspen Institute

Welcome — **Roger Ballentine**, President, Green Strategies Inc.

Jim Connaughton, President and CEO, Nautilus Data Technologies

SESSION I: **The Data Room: Overview of the Clean Energy Landscape**

How has the clean energy landscape shifted over the last year, and where is it projected to be over the next five years? This session will present an overview of clean energy development, electrification, capital flows, and decarbonization in the US and globally.

Moderators: Roger Ballentine and **Jim Connaughton**

Discussants:

Richard Newell, Resources for the Future
Jeff Weiss, Distributed Sun
Martha Symko-Davies, NREL

SESSION II: **Is 100% Not Enough? Market and Policy Shifts towards Zero-Carbon**

Along with natural gas, renewables have significantly contributed to decarbonizing the electricity sector over the last decade. The proliferation of wind and solar in particular has been driven by policy, declining costs, and corporate demand. While we remain a long way from the deeper decarbonization of the electricity sector, what are the latest trends in corporate clean energy goals and procurement? Will companies and stakeholders choose to support 100% RE or 100% clean energy? What are the market and regulatory pathways and obstacles and what state and federal policy is needed?

Moderator: Roger Ballentine

Discussants:

Armond Cohen, Clean Air Task Force
Mars Hanna, Google
Jon Sohn, Capital Power
Miranda Ballentine, REBA

SESSION III: **Transformational Technology**

Satisfying clean energy policy objectives, decarbonization goals, changing customer demands, growing security concerns, and replacing aging infrastructure, all can be aided by new transformational technologies and new business models and systems-based approaches. How can technology development and deployment keep pace with these changing objectives? What are the key technologies needed and what resources and incentives are needed to bring them to market?

Moderator: Jim Connaughton

Discussants:

Dave Danielson, Breakthrough Energy Ventures
Paul Camuti, Ingersoll Rand
Rick Counihan, Google
Sonny Garg, Uptake

SESSION IV: **Distributed Disruption: The Changing State of Distribution Grids and Retail Markets**

Once an experiment in a few states, fundamental changes to the way distribution grids are managed and retail markets are regulated are underway or under consideration in states across the country. Evolving customer expectations, environmental imperatives, enhanced uses of data, the proliferation of distributed energy resources (DERs), changing rate designs, and new approaches to the scope of monopolistic functions, are all impacting functioning of retail markets and distribution grid planning. What technologies are needed for the next generation of retail market structures? How are distribution grid investments changing and who are the winners and losers? Are regulators leading or lagging? What is the end game?

Moderator: Roger Ballentine

Discussants:

Jeff Ackermann, Colorado PUC
Lynne Kiesling, Purdue University
Steph Speirs, Solstice
Chris Herbst, Eaton

TUESDAY, FEBRUARY 26

SESSION V: **Drilling Deeper into FERC and Wholesale Markets**

Economic-driven changes in generation types, state policies that impact wholesale markets and price formation, new technologies, and federal efforts to manage change while ensuring just and cost-effective transitions, are putting FERC into a spotlight. What is the current state of regulatory action at the state and federal levels? Where is there unfinished business and potential for RTO expansion? How is FERC's role changing and should it be the driver or the manager of change in wholesale markets?

Moderator: Jim Connaughton

Discussants:

Chairman Neil Chatterjee, FERC
Brian Marrs, Microsoft
Jason Barker, Exelon

SESSION VI: **Climate Policy – and Politics – in the Next Congress and 2020 Presidential Race**

With a Democratic House, a Republican Senate, and the 2020 Presidential campaign starting, climate is now in the middle of policy and political dialogues more than any time since 2009. What are the political dynamics and realities of the next two years? How could clean energy or climate legislation be passed in the next two years or beyond that? How should social equity, justice, and the urban-rural divide be considered in policy development?

Moderatos: Roger Ballentine and **Jim Connaughton**

Discussants:

Bill Ritter, Colorado State University
Nat Simons, Sea Change Foundation
Michelle Patron, Microsoft
Rich Powell, ClearPath

Closing Session: Wrap Up – Reaching the Gigaton Level

DECARBONIZING BEYOND ELECTRICITY TRACK: GETTING TO ZERO AND BEYOND

WEDNESDAY, FEBRUARY 27

Opening Session

Introduction — **Greg Gershuny**, Interim Director, Energy & Environment Program, The Aspen Institute

Welcome — **Roger Ballentine**, President, Green Strategies Inc.

SESSION I: **Matching a Big Challenge with Big Ideas: Gigaton-Scale Solutions**

The challenge of meeting a science-based target for global decarbonization across all sectors can seem daunting. How do current pathways across sectors align with this level of ambition? How far does each sector have to go to contribute to this goal? What are the current signals from US and foreign capital markets in terms of momentum and caution? And what are the big ideas that can move markets, politics, and social will toward more aggressive decarbonization pathways across sectors?

Moderator: Roger Ballentine

Discussants:

John Larsen, Rhodium Group
Michael Picker, California PUC
Amory Lovins, RMI

SESSION II: **Pathways to Decarbonizing the Transportation Sector**

Transportation recently surpassed the electricity sector as the largest contributor of greenhouse gas emissions in the US. What is the current outlook for reducing transport sector emissions? How can light and heavy-duty vehicles, aviation, and shipping industries contribute to decarbonization?

Moderator: Greg Gershuny

Discussants:

Mitch Jackson, FedEx
Rohan Patel, Tesla
Jenna Weatherred, Holy Cross Energy

SESSION III: **A New Revolution: Decarbonizing the Industrial Sector**

Industrial processes are often considered the most difficult to decarbonize. How can production of cement, steel, plastics, and other materials transition to low-carbon processes, and what will the impacts be to cost and price? Can decarbonization align with improving competitiveness and job creation in the industrial sector?

Moderator: Roger Ballentine

Discussants:

Drew Nelson, Cynthia & George Mitchell Foundation
Dave Danielson, Breakthrough Energy Ventures

SESSION IV: **Carbon Capture and Removal Solutions**

There are many innovative ideas, methods, and solutions for carbon capture technologies. Storage, utilization, bioenergy, and sequestration are all viable options. What role will carbon removal play in economy-wide decarbonization? How can CCS technologies continue to be improved and commercialized?

Moderator: Roger Ballentine

Discussants:

Giana Amador, Carbon180
Bill Brown, NET Power
Jen Wilcox, Worcester Polytechnic Institute
Al Collins, Occidental Petroleum Corporation

THURSDAY, FEBRUARY 28

SESSION V: **Navigating the Political and Policy Landscape: How We Bring Disparate Sectors Together in Support of Comprehensive Climate Policy**

Previous policy mechanisms, such as the Clean Power Plan, have demonstrated pathways for decarbonization in the electricity sector; CAFÉ, tailpipe emission standards, and emerging state and federal policies could lead to electric vehicle infrastructure. But we don't have as developed policy and political coalitions in place to address heavy industry, agriculture, buildings, and other key sectors that represent a full menu of options for economy-wide decarbonization. How do we expand the coalition of the willing? Which policies are most conducive to decarbonizing each sector? Does carbon pricing offer an adequate pathway?

Moderators: Greg Gershuny and Roger Ballentine

Discussants:

Richard Newell, Resources for the Future
Erin Burns, Carbon180
Justin Segall, Simple Energy
Matt Baker, Hewlett

10:30 – 11:00 AM **Closing Session: Wrap Up**

PARTICIPANTS

CLEAN ELECTRICITY TRACK: GETTING TO ZERO

Roger Ballentine, President, Green Strategies Inc. (*Co-Chair*)

James Connaughton, President & CEO, Nautilus Data Technologies (*Co-Chair*)

Jeffrey Ackermann, Chairman, Colorado Public Utilities Commission

Lindsay Baker, Head of Sustainability & Wellbeing, WeWork

Miranda Ballentine, CEO, Renewable Energy Buyers Alliance

Jason Barker, Director, Wholesale Market Development, Exelon Corporation

Morgan Bazilian, Executive Director, Payne Institute; Professor of Public Policy, Colorado School of Mines

Stephen Beuning, Vice President, Power Supply, Holy Cross Energy

Samuel Brothwell, Director of Research, Energy Income Partners, LLC

Bill Brown, CEO, NET Power, LLC

Michael Bruce, Director, Emerson Elemental

Paul Camuti, Senior Vice President, Innovation & Chief Technology Officer, Ingersoll Rand

Neil Chatterjee, Chairman, Federal Energy Regulatory Commission

Steve Clemmer, Director of Energy Research & Analysis, Union of Concerned Scientists

Armond Cohen, Executive Director, Clean Air Task Force

Al Collins, Senior Director, Regulatory Affairs, Occidental Petroleum Corporation

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