2020 ASPEN - COLUMBIA ENERGY WEEK

BUILDING A CLEAN ENERGY SOCIETY: DEPLOYING & SCALING A ZERO-CARBON FUTURE

A Report from
2020 Aspen-Columbia Energy Week

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EXECUTIVE SUMMARY

2020 has been an unprecedented year in many respects, including political, societal, public health, and economic upheaval. It has also been unprecedented with respect to climate and energy. In addition to headline-grabbing climate impacts happening around the world, technologies are emerging and beginning to scale, finance mechanisms are being developed, and decarbonization commitments are being made in ways that would have been unimaginable a few years ago.

As with numerous other parts of global life, the COVID-19 pandemic has caused tumult in energy markets. Fuel demand dropped precipitously, especially for jet fuel. Vehicle sales cratered, though electric vehicles (EVs) fared better than global auto sales as a whole. Public transportation systems saw massive cuts in ridership and revenue. The power sector saw a shift in demand from commercial to residential buildings, as well as negative impacts on coal. The U.S. steel industry took a hard hit. Clean energy technologies dependent on global supply chains were challenged by COVID and the recession. While the COVID-related shifts in energy led to a fairly sizable drop in greenhouse gas (GHG) emissions, emissions are rising again as demand returns. Emission reductions will only be solidified if there is change in the underlying structures of the energy system, but governments adopting safety net and stimulus packages are generally failing to devote enough attention or money to the paradigm of economic recovery through clean energy and climate solutions.

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Achieving an affordable economy-wide zero-carbon transition depends on an accelerated response from the power sector. Renewables now account for most new power projects, and costs have come down dramatically and continue to decline. Renewables and hybrid systems that pair renewables with batteries (or other technologies) are already starting to provide advanced grid services. More is needed, though, including expanded transmission and flexible, dispatchable zero-emissions technologies such as hydrogen, storage, nuclear power (both existing and advanced reactors), and carbon capture, utilization, and storage (CCUS). Distributed energy resources (DERs) – such as rooftop solar, EV batteries, and advanced water heaters – can also be part of the carbon abatement equation if they can be made cyber-secure, with demand response playing a particularly important role in advancing demand flexibility. The volume of new technologies and zero-marginal-cost renewables coming onto the grid suggests a need to reform wholesale markets to incentivize investment in and properly value the technologies needed for decarbonization. Retail markets, meanwhile, need to change pricing structures from a scarcity mindset to an abundance mindset, to shift consumption to periods of abundant renewable generation.

The transportation sector also plays a central role in decarbonization. The main strategy to address transport emissions, particularly from light-duty vehicles, is electrification – a focus spurred by significant declines in battery costs. Public investments, though, may be too focused on personal EVs and not focused enough on support for EV fleets, which can expand access to EVs and move more people around in a sustainable manner. It is important to reduce vehicle use and vehicle-miles traveled (VMT) while increasing accessibility – such as through public transit. More time, effort, and money need to be spent making transit available to the vast majority of the population and to enable transit to serve a wider range of transportation needs. Decarbonizing freight transportation – whether via air, ship, rail, or truck – can also drive greenhouse gas (GHG) reductions, air quality improvements, and public health gains across the globe, including in developing nations and pollution-burdened communities. In addition to efficiency, freight decarbonization options include electrification, hydrogen, ammonia, and other fuels, though there are hurdles related to cost and infrastructure. Beyond tailpipes, transportation is also one of the largest users of GHG-intensive materials, so there may be a need to rethink transportation systems, infrastructure, land use, and communities more broadly to reduce the number of vehicles and the amount of roadbuilding necessary to serve mobility needs, as well as to reduce the transportation system's numerous other impacts on health, environment, equity, and quality of life.

Heavy industry, another huge source of global GHG emissions, is very reliant on fossil fuels to generate high-temperature heat. Hydrogen can substitute for fossil fuels in many processes, but to advance decarbonization, it needs to be zero-carbon hydrogen, which is currently pretty expensive and would require large investments in infrastructure. Still, clean hydrogen is showing signs of beginning to scale up. Other technologies worth pursuing to decarbonize industrial heat include biomass, electrification, CCUS, and potentially advanced nuclear. For the steel industry, promising opportunities for decarbonization include electrification of production, use of hydrogen as a reductant, CCUS, and substitution with other materials such as cross-laminated timber. Industrial processing involves lots of wasted heat, resources, and electricity, so efficiency also has a big role to play in reducing industrial emissions, though manufacturers are often averse to changing established assets and processes. The transition to a low-carbon industrial sector should be very affordable from a macroeconomic perspective, since materials are responsible for only a tiny portion of the cost of finished goods and projects, but the upfront capital costs to decarbonize industry are non-trivial. It is therefore critical to create market pull for commodities that have zero (or near-zero) emissions associated with their production, such as through public and private procurement policies, standards for what counts as a low-carbon product, and tradable markets for low-carbon products. Decarbonization is important to achieve in U.S. industry, but decarbonization activities are particularly needed in the large and growing industrial sectors in China and India.

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In addition to reducing emissions, it is also essential to take carbon dioxide (CO_2) out of the air and the oceans and/or to divert it for productive use. It is likely to be carbon dioxide removal (CDR) that puts the "net" into "net zero", and analyses suggest that CDR will have to ramp up from thousands of tons now to billions per year by mid-century. CDR can take various forms, but the main ones include nature-based solutions, bioenergy with carbon capture and storage (BECCS), and direct air capture (DAC). DAC is currently the most expensive version of CDR, but as its costs come down, DAC will create a fallback maximum cost to achieve ambitious net-zero targets. CDR is not a substitute for the rest of mitigation, but any delays or failures on any other mitigation front will require more CDR. People are really only beginning to think about CDR in a serious way, and there is a huge amount to do on an innovation and research agenda. It is also critically important to get capital for putting up CDR plants to enable learning-by-doing and cost reductions; this will require government leadership (including procurement), as well as capital from investors and large corporates. The carbon dioxide captured from the atmosphere, from power plants, or from other point sources has the potential to be turned into market commodities. There is a lot of emerging technology for utilizing captured CO_2, including to produce methanol, cure cement, make carbon fibers and polymers, create aggregates, and – the biggest in terms of climate impact, but still furthest from achieving scale – making liquid fuels. The costs of carbon utilization have to be driven down further, such as through using curtailed renewables, utilizing existing manufacturing plants, modernizing Scope 3 emissions accounting, and enhancing policy support and public procurement.

Buildings, neighborhoods, and cities are where the various sectoral elements come together and thus are a core aspect of the decarbonization challenge. Decarbonizing buildings involves advancing energy efficiency, electrification, and digitization. There is also now an opportunity to reimagine neighborhoods and cities to be less centered around cars and to be better for people and the planet. The concept of "smart cities" and "smart communities", for instance, seeks to leverage technology to modernize digital, physical, and social infrastructure in an integrated manner, in order to make the delivery of essential services more efficient, sustainable, cost-effective, secure, equitable, and reliable. Sensors, telecommunications, smart street lights, building energy management systems, and more will change cities and energy systems, and there is a need to integrate telecommunications, advanced mobility, building design, and much more in a way that is not being done thoughtfully now. Creating smart cities in this time of multiple disruptions will require leadership, urgency, and creativity, especially regarding financing.

In cities and elsewhere, achieving economy-wide decarbonization will require building a lot of infrastructure – including transmission and distribution systems, EV charging stations, and hydrogen and CO2 pipelines – but ambitious emission reduction targets may be impossible to achieve under current regulatory and permitting structures at the local, state, and federal levels. There are tradeoffs between process and speed, but it is essential to get to 'yes' or 'no' more quickly on projects. States have pursued some reforms, but some kind of federal compromise on the National Environmental Policy Act (NEPA) is needed to allow decarbonization projects to move forward more quickly (while still having to comply fully with all federal, state, and local environmental, health, and safety laws). Getting the needed infrastructure built will also require substantial public and private investment, which could involve roles for green banks, green bonds, and other financial actors and vehicles. Green finance now seems to be available and cheap, and there are more and more signals for climate action in the capital markets. Policy can send signals to invest in needed infrastructure, as well as to incentivize retirement of high-emitting infrastructure.

Tackling the climate crisis will involve a combination of deploying existing technologies at an unprecedented scale and rapidly developing nascent technologies.

Tackling the climate crisis will involve a combination of deploying existing technologies at an unprecedented scale and rapidly developing nascent technologies. There are numerous technologies that already exist, at various degrees of maturity and scale, to promote decarbonization in particular sectors, but there are also cross-sectoral opportunities. Hurdles to achieving deployment at scale must be overcome, such as by thinking about the appropriate role of public utilities, governmental bodies, and other institutions in de-risking deployment of technologies that involve waste disposal (e.g., nuclear, CCS). Scale can happen quickly, though; while past energy transitions have been slow, this transition may not follow suit. Since many of the emission reductions needed to achieve net-zero may come from technologies that have not yet reached markets, continued research, development, and demonstration (RD&D) are also needed to bring nascent technologies to the point of readiness to scale. The U.S. national labs are already working and collaborating quite actively on existing and innovative technologies, energy systems integration, innovation incubators, cybersecurity, and more, but additional federal support for clean energy RD&D is needed, including big increases in RD&D funding that are mapped to critical decarbonization needs and that bridge sectors, actors, and geographies.

The federal government needs to start paying more attention to climate resilience as well, particularly in vulnerable regions and communities. Resilience is defined by the weakest links in the chain; it takes just one jurisdiction where critical infrastructure fails for an event to have a devastating toll. The resilience of U.S. energy infrastructure is moderate at best, and climate-related stressors on that infrastructure are growing in frequency and intensity. Utilities are therefore investing in resilience, running scenarios, utilizing sensors and broadband technologies, and harnessing decentralized energy resources. The costs of resilience investments are high, but the costs of failing to make those investments are far higher, and it is important to quantify and consider all such costs, thinking about resilience in broad societal terms. More federal resilience funding is certainly needed, but existing sources of funding and authority also need to work together better so the system is less complex and more local communities can access it. To improve coordination, a cross-agency initiative is needed, with local community voices centered, to bring people together to share information and encourage collaboration among jurisdictions, across levels of government, and across sectors.

The recent spotlight on vulnerable communities and systemic inequities is also raising direct questions about how to make the zero-carbon transition not only rapid, but also equitable and just, particularly for communities of color, low-income communities, and rural communities. Responses to the climate challenge could either widen or narrow existing equity gaps, with profound effects on health and well-being, so it is vital that the people in these communities are sitting at the table when decisions are studied and made. There is a need to be as attentive to policies that address equity concerns, bring people in, and build the coalition needed to perpetuate the clean energy transition as to policies directly focused on decarbonization. There have been efforts to advance equity in climate solutions, including with regard to clean energy and electrified transport in disadvantaged and pollution-burdened communities, as well as in the operation of market-based policies. The environmental justice community, though, has generally distrusted market-based approaches to addressing climate change, preferring mandates to reduce emissions from the sources having the biggest air pollution health impacts in communities. Equity and justice issues have to be brought into thinking around power market design and power market governance as well. In addition, communities reliant on emitting fuels and industries that will experience negative economic impacts from the transition will also need support, though they have heard unfulfilled promises of a "just transition" for too long.

Responses to the climate challenge could either widen or narrow existing equity gaps, with profound effects on health and well-being, so it is vital that the people in these communities are sitting at the table when decisions are studied and made.

In the corporate arena, 2020 has seen a wave of major announcements of companies making commitments to zero-carbon and other clean energy goals, including both buyers and producers of energy, and most major U.S. utilities have now made such commitments. These corporate goals are getting more ambitious, in terms of the numerical targets, achievement dates, scope of considered emissions, and plans to achieve granular, real-time, 24/7/365 carbon-free energy at each place where corporate facilities are located. It is not clear today how all of these goals will be achieved; the companies need technologies, infrastructure, policies, financing, data, and advanced analytics, tools, and visualizations to create implementable blueprints to get there. When corporate leaders put these sorts of targets and initiatives out in the public sphere, they can spur discussions, help others consider and adopt similar goals, and create momentum and demand in the market for new solutions. In addition to bringing clean power to market, companies are also deploying electric vehicles in large numbers, advancing energy efficiency, and, in a few cases, announcing funds to invest in novel climate solutions. Climate change is a systemic problem, though, and there are limits to what even the largest individual companies can do, so corporate leadership has to start including a greater focus on policy advocacy too.

The policies that the United States may utilize to address climate change hinge on the outcomes of the November 2020 presidential and congressional elections. Assuming the House remains under Democratic control, the question is whether it will have partners in the White House and the Senate for bold climate action. Democrats currently seem more focused on standards to move particular sectors and on driving clean energy investment than on carbon pricing. While there are still some Republicans who espouse climate denial, they are fewer and have less influence in Congress than in the past. There has been some budding bipartisanship around the acknowledgment of climate change as an issue to grapple with, and there may be room for more, including on issues of resilience, agriculture, and innovation. While domestic climate action is critical, the United States also has to focus on affecting the development trajectory of the rest of the world. The United States, however, is far behind global competitors such as China and Russia in taking advantage of the opportunities to sell and build energy infrastructure, including advanced nuclear, in the global energy growth markets. There is a vital role for public policy tools such as the ones the International Development Finance Corporation and U.S. Export-Import Bank provide to help de-risk investments. There could also be bipartisan support for joining trade, climate, and clean energy policy into a common framework that factors in embodied carbon and helps emerging economies develop on a cleaner path.

A WORLD RESHAPED BY COVID-19

As with numerous other parts of global life, the COVID-19 pandemic has led to tumultuous times in energy markets.

IMPACTS

The largest energy impact of COVID-19 has been in the transportation sector. In the United States, starting around March or April 2020, personal mobility declined dramatically. At its lowest, gasoline demand was halved, and jet fuel demand was down by even more. Combined with supply issues, global oil prices collapsed, leading in turn to significant restructuring in the oil industry. Prices and demand have both recovered somewhat, sometimes back near pre-pandemic levels, though jet fuel demand is still lagging.

Vehicle sales also cratered, though sales of electric vehicles (EVs) dropped much less in the first half of 2020 than global auto sales as a whole. This is partly a consequence of the disparate impacts of the COVID-induced economic recession. The recession has affected high-income households and knowledge-economy workers much less than low-income households and service-sector workers, so buyers of higher-end low-carbon devices such as EVs have been in relatively better positions.

Combined, these trends have manifested in dramatic changes in the market valuation of companies in those sectors. A year ago, the combined market cap of the three largest U.S. oil producers (ExxonMobil, Chevron, and ConocoPhillips) was far above that of EV maker Tesla; in 2020, Tesla is worth more than those three oil producers combined. The major players in the energy system could well change due to the zero-carbon transition.

Public transportation systems have also seen massive cuts in ridership and revenue, as many people work from home and shift to cars out of fear of virus exposure.

Outside of the transportation sector, the impact in the power sector has mostly been a shift in demand from commercial to residential buildings, as well as further negative impacts on coal. In the industrial sector, the largest impact from an energy standpoint has been in the steel industry, especially in the United States, where the shock in the first half of the year closed several mills. Chemicals, cement, and some other sectors rebounded quickly. More broadly, many clean energy technologies are dependent on global supply chains that have been affected by COVID and the recession in a range of ways.

The COVID-related shifts in energy led to a fairly sizable drop in greenhouse gas (GHG) emissions, but emissions are already returning as demand returns. Emission reductions will only be solidified if there is change in the underlying structures of the energy system.

It remains unclear whether and to what extent the changes in demand patterns in 2020 will endure post-COVID. Will telecommuting become more of a norm, and if so, for what percentage of the workforce and with what implications for energy demand? Will public transportation systems receive the additional investment they desperately need, or will they be left to wither, which could have serious equity implications? Will transportation trends persist after vaccines and treatments become available, or will demand patterns shift back closer to what they were pre-pandemic?

RECOVERY

In response to the economic contraction due to the pandemic, governments are adopting a range of safety net and stimulus packages, but the paradigm of economic recovery through clean energy is not getting enough attention or money. As of July, the United States had spent the most on recovery as a share of GDP – slightly more than Europe and much more than China and India – but, of the four, had the smallest share of its stimulus directed toward clean energy, slightly behind China and India. Clearly, the prioritization in the United States could change depending on the outcome of the November elections. Investments in clean energy infrastructure can be a key way to rebuild economies coming out of the pandemic, but the EU has been an outlier in using recovery funding as a vehicle for shoring up and accelerating the deployment of clean energy technology. It is important to try to recover from the pandemic in ways that also help solve the climate crisis.

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POWER SECTOR

In combination with the impacts of extreme events such as wildfires and storms, COVID has made clear the critical role that reliable, secure electricity supplies play in everyday life to power communications, health care, supply chains, and much more. The power sector is the backbone of modern life. It is also the backbone of decarbonization.

DECARBONIZATION OF POWER

Any reputable scenario for achieving an affordable economy-wide zero-carbon transition depends on an accelerated response from the power sector. The transition to a zero-carbon electricity system appears to be underway, through a more decentralized, digitalized, and decarbonized model.

In the United States, the power sector is transforming, with renewables accounting for a sizable majority of new projects. A decade ago, there might have been tensions between regulators' requirements for utilities to provide low-cost service and policymakers' desires for more renewable electricity, but renewables' costs have come down so much that, in many regions, consumers could save money by switching to clean energy, not spend more. Costs for renewables are continuing to decline too. Even so, sustaining the tax incentives that are currently available to renewable technologies, rather than letting them expire or step down, could provide key support for continued decarbonization. Enabling direct-pay mechanisms for the tax credits could also be a crucial bridge in getting people back to work in the renewables industry, particularly in the face of uncertainty about the tax equity supply during the pandemic. There are concerns, though, that if the energy transition is pushed too quickly by aggressive targets, the cost curves for storage and other technologies will not have enough time to decline sufficiently, which could make the transition more expensive and lead energy costs to rise.

The transition to a zero-carbon electricity system appears to be underway, through a more decentralized, digitalized, and decarbonized model.

Clean technologies are advancing rapidly, beyond traditional understandings of what wind, solar, and batteries can do. Already, renewables and hybrid systems that pair renewables with batteries (or other technologies) are starting to provide advanced grid services, such as ramping controls and fast frequency response. There are examples of requests for proposals (RFPs) in the United States and around the world for 24/7 dispatchable net-zero systems – and responses to those RFPs, with developers creatively combining wind, solar, storage, and other technologies with load-side devices and advanced algorithms. A new phase of clean technology solutions appears to be underway.

More is needed, though. For instance, transmission is vital. It has to be made easier to get renewably generated electrons – both onshore and offshore – to the locations with the demand loads. In some places, it may be possible to use existing rights of way and repower the existing power lines.

In addition, even with a lot more renewables, there will be a need in many areas for some other kind of flexible, reliable, dispatchable, affordable zero-emissions technologies in the mix, probably somewhere in the 2030-2040 timeframe. These technologies could involve nuclear power, hydrogen, carbon capture and storage (CCS), various types of storage, or other technologies. The technologies are developing rapidly. Seasonal storage may be a reality within the next few years, zero-carbon hydrogen projects are starting to get underway, and advanced nuclear reactors are progressing through the Nuclear Regulatory Commission (NRC) processes.

NUCLEAR

At some point in the continual societal rebalancing of preferences and factors, the need for rapid decarbonization may overtake people's particularities about how best to achieve it. In the meantime, mixed feelings or hostility about nuclear power have kept it from being fully embraced by all as part of the decarbonization toolkit, though nuclear has made some progress in that regard.

Maintaining the existing zero-carbon resources in the power mix seems like an obvious starting point, but the existing nuclear fleet is retiring prematurely due to economic forces, mostly in organized markets. The markets are telling these plants to shut down, but policies could provide financial support to help sustain the clean generation already in place, at a cost lower than is being paid for some other zero-carbon generation sources (e.g., rooftop solar).

There has also been lots of investment, both public and private, in new advanced nuclear technologies, and companies are exploring several different pathways, often drawing on past technologies that were never commercialized. Many of these systems are small or micro, flexible, and dispatchable, which should fit better in a future energy system with lots of variable renewable generation. There is a need to be cautious about prematurely down-selecting the technological field, even though having numerous competing technologies dilutes the impact of the government and private investment in the space.

The key question about new nuclear is whether it can be deployed and scaled at the needed pace. If advanced nuclear technologies are going to play a role in achieving a clean energy economy in a timeframe commensurate with the warnings of climate scientists, there is a need to re-examine and challenge the traditional orthodoxies about how to approach deployment. That may mean examining how best to direct federal assistance and funding so as to support (and not distort) the significant private capital flowing into the space.

If advanced nuclear technologies are going to play a role in achieving a clean energy economy in a timeframe commensurate with the warnings of climate scientists, there is a need to re-examine and challenge the traditional orthodoxies about how to approach deployment.

The federal government has improved access to the national labs for those working on advanced nuclear technologies. Unlike even a decade ago, the national labs are now serving as a ready access point and partner for multiple innovative private companies. Even so, some wonder whether that is the optimal model or if some different kind of public-private collaboration would create a better ecosystem for nuclear developers.

Congress has also supported increased investment in clean energy innovation in recent years, including in advanced nuclear (as well as in CCUS and other technologies), yet there has been some challenge in getting private capital off the sidelines. Many investors find the notion of bureaucratic government involvement to be a big turnoff, yet nuclear power, somewhat uniquely, always requires a strong government presence and government controls, given the security risks linked to its fuel. To secure more private investment, the current process will have to be accelerated; investors will not go for a project that requires a decade to get a license. While the NRC recently certified the design of a small modular reactor for the first time, it is not clear that the regulatory apparatus can be fundamentally redesigned on the timeframes needed to get advanced nuclear technologies commercialized at scale to achieve climate goals.

DISTRIBUTED ENERGY RESOURCES & DEMAND RESPONSE

The electricity industry has been based on big long-term investments in assets that can last decades, but more types of technology are being blended into the system, both utility-scale and distributed. Distributed energy resources (DERs) – such as rooftop solar, electric vehicles batteries, and advanced water heaters – can be part of the carbon abatement equation. For instance, DERs with storage, including EVs, open up exciting opportunities for distributed mini- and micro-grids. In September 2020, the Federal Energy Regulatory Commission (FERC) adopted Order 2222 removing wholesale market barriers to aggregated DERs, finding that aggregations of these smaller energy assets should be able to join together via technology and compete in wholesale electricity markets just like a large power plant. The order might help shift transmission investments, as DERs bring flexibility to the grid.

As other sectors are electrified to advance decarbonization, it will be even more important to enhance energy efficiency efforts, boost demand response, and improve orchestration of the various resources on the system (in front of and behind the meter) to manage that load.

The demand response element of DERs, in particular, will be key to achieving decarbonization goals, as the demand flexibility that DERs provide can enable peak shaving, greater use of renewables, and more. Demand response is something that is available now that can yield early gains in emission reductions. Price signals play a role; customers on time-of-use rates get a price signal on their distributed devices to conserve power when demand peaks, which can lead to lots of megawatts of residential load being shaved off the system, eliminating the need for some peaker plants to come online. There may be significant untapped potential in the commercial and industrial demand response space too, as well as huge potential for load shifting and peak shaving from thermal approaches (e.g., using solar energy at its peak to precool buildings). Better alignment between demand and supply could also reduce costs. Much of the electricity system has traditionally been based around supply needing to be responsive to demand, but with more variable renewable generation, there is a need to think about how to have demand be more responsive to supply. The electricity system holds a large amount of capacity to accommodate a few days per year of demand spikes, which means poor utilization of assets. If demand peaks can be shaved and demand flexibility improved, such as through digital platforms and orchestration of connected devices, capacity could be reduced, which could take costs out of the system.

As the grid becomes more bi-directional with both centralized and distributed energy resources, and as more variable renewable generation comes online, there will be big increases in the amount and variety of data to collect, communicate, and analyze rapidly. Some question whether DERs will prove valuable enough to decarbonization to be worth the cybersecurity issues raised when huge numbers of unhardened devices are put on and communicate with the critical infrastructure of the grid, but as the grid is modernized, there are opportunities to deploy wireless spectrum technologies, such as private LTE networks, in cyber-secure ways. A private LTE network can also allow for DER control (and thus demand flexibility) across a system, mitigating the need to build broadband and fiber to the outer reaches of some rural areas.

As other sectors are electrified to advance decarbonization, it will be even more important to enhance energy efficiency efforts, boost demand response, and improve orchestration of the various resources on the system (in front of and behind the meter) to manage that load. To be successful, utilities have to partner, improve communications and delivery systems, and allow many technologies onto the grid in a way that is both secure and affordable.

POWER MARKETS

Power sector technologies have developed and changed significantly since the 1990s, but that is the last time the electricity market structure in the United States was reworked. To achieve deep decarbonization and take fuller advantage of available and emerging technologies, electricity markets may need to be restructured again and brought into the 21st century.

There has never been anything close to the transformational change that zero-marginal cost renewables are forcing in power markets. Apart from two instances over the past century – hydro in the 1920s and nuclear in the 1970s – innovation in the sector has largely consisted of slightly more efficient combustion, which made it relatively easy to figure out pricing based on marginal cost. The way it has been done for decades, though, no longer works when gigawatts of zero-marginal-cost renewables enter the picture. Incremental interventions in capacity and energy markets are not getting at the fundamental problems presented by zero-marginal-cost energy resources. Markets need to respond to how fast technology is changing. There is a need to reform wholesale markets but also to recognize the value of markets to deliver cost-effective results and spur innovation via competition. Markets need to be sending the private sector the right signals to invest in the right technologies, which can accelerate the transition.

Wholesale markets can help harmonize various state policies, but that requires viewing the role of wholesale markets as recognizing and ideally facilitating state policies, which can set the boundaries for the markets to operate within.

It is unclear what power market structures are needed to support the technologies of a decarbonized future, but there is a need to take a more holistic look at market design. The markets might need a new objective function and a new timeframe. Lowest short-run marginal cost may no longer be the right objective, and given the short timeframe available to drastically reduce emissions and the long lifetimes of energy infrastructure, emissions-free resources may need to get elevated priority in all grid decisions.

It does not seem like markets are properly valuing resources today. Baseload generation is valued perhaps more than it should be, while there are huge opportunities for efficiency, conservation, demand response, and optimization in the system that are not being harvested. Grid-support attributes and capabilities of clean energy technologies, perhaps especially solar-plus-storage, also need to be better reflected in market rules. For example, storage is widely acknowledged as a necessary technology and can play lots of different roles, but there are very poor price signals in markets to justify huge investments. Without knowing how storage will be valued, it becomes a riskier bet; innovation is needed on revenue streams and market recognition of the multiple values storage can provide. There has to be a way to provide price signals to encourage innovation and deployment; the markets could, for instance, provide a value for flexibility and compensate whichever technologies provide it. The markets, designed for what was needed in the past, are now incentivizing the wrong things.

Capacity markets also over-procure capacity. If energy prices were allowed to go as high as needed, there would be no need for capacity markets, but state policymakers, governors, utility commissioners, consumer advocates, and others in some regions are not willing to let energy prices soar; tolerances for scarcity pricing in the Northeast and Texas are very different. Texas has an energy-only market, the eastern regional transmission organizations (RTOs) and independent system operators (ISOs) have mandatory capacity markets, and the Midwest and others have hybrids (which may be worth examining further).

Some wonder whether it is in the national interest – and necessary to meeting the low-carbon challenge – to have all states be in organized markets. Two-thirds of Americans are in wholesale markets, and even states in regions without organized markets are at least exploring the idea of working together better on a regional basis. The Western and Southeastern states are moving forward incrementally toward organized markets (though Western utilities are maintaining the balkanized self-evaluation of grid access and interconnection). Forced regionalization and market participation do not appear to be on the horizon any time soon, but true organized markets may not occur voluntarily. For instance, some utilities in the Southeast will never consider a true organized wholesale market given recent FERC orders such as the Minimum Offer Price Rule (MOPR); they fear the loss of control.

Indeed, there has been lots of pushback recently against organized markets due to the conflict between state policy and FERC regulation. Some regions with mandatory capacity markets have been subject to FERC rules such as MOPR that make it harder for state-supported clean energy resources to participate and that undermine state policies to reduce

Retail markets, meanwhile, structure pricing around a scarcity mindset, but a shift is needed to an abundance mindset.

emissions. Some states now have open dockets and actual proposals on the table to pull out of the capacity markets and take back responsibility for resource adequacy. Federal regulations should accommodate and not block state policies. Wholesale markets can help harmonize various state policies, but that requires viewing the role of wholesale markets as recognizing and ideally facilitating state policies, which can set the boundaries for the markets to operate within. There is a need to figure out a better way to address legitimate market needs but to ensure that states choose the resources they think are best for them moving forward.

Carbon pricing in power markets can be one way to address some state concerns. FERC is not an environmental regulator, and it did not weigh in on sulfur dioxide, mercury, or other pollutants, but unlike those pollutants, there are no federal limits on carbon dioxide, which has led numerous states to take up their own measures. That necessarily brings FERC into the mix. If some states within a market are pursuing carbon pricing while others in that market are not, FERC will have to figure out how to address that situation and have pricing reflected in wholesale markets. FERC held a technical conference in late September 2020 to look at carbon pricing in wholesale markets and to have a frank discussion about what happens when states or regions adopt carbon pricing. The conference highlighted the consensus and enthusiasm around market-oriented solutions. It appears that FERC has authority under the Federal Power Act to evaluate the justness and reasonableness of an RTO proposal to incorporate a state-imposed carbon price in its tariff.

Retail markets, meanwhile, structure pricing around a scarcity mindset, but a shift is needed to an abundance mindset. For instance, in areas of solar abundance (e.g., the West), the price patterns on the wholesale market are rather predictable, with prices staying low until mid- to late-afternoon, when demand and price go up. A retail rate design that focuses on abundance could shift consumption to the early afternoon period, pre-cool homes, and then leave air conditioning systems off after that. Some utilities will soon have so much electricity during mid-day solar hours that they will be giving it away essentially for free. Retail price signals can play a big role.

TRANSPORTATION

Sectors of the economy beyond the electric power system will need to be transformed to achieve a low-carbon future. The transportation sector, in particular, plays an important role in decarbonization.

ELECTRIFICATION

From a climate perspective, the main global strategy to address transport emissions, particularly from light-duty vehicles, is electrification. Electrification of transport usually refers primarily to battery-electric vehicles, but the term can also include hydrogen fuel cell vehicles and, potentially, the production of electric fuels (i.e., power-to-fuels).

Analyses suggest the electrification of transport should not cost much money. Within a few years, the total cost of ownership of electric light-duty vehicles (and many trucks) will be equal to or below conventional options, due to battery costs coming down so quickly. Of course, almost no one makes consumer decisions based on total cost of ownership, and the current up-front cost premiums for EVs and the lack of access to ubiquitous charging are significant barriers. Costs of EVs will likely be higher than conventional vehicles for a few more years, which is why policies (e.g., feebates) are important to change the price signals and encourage cleaner choices. Still, from an economic perspective, electrification of transport is not a high-cost strategy – and may soon be an economically beneficial one (not even taking into account avoided health costs, climate impacts, and other externalities).

National and state level EV mandates and incentives could drive serious investment, innovation, and experimentation.

Drivers on rideshare platforms could be a good group of people to accelerate adoption of EVs. Because of the very high mileages they are driving and a slightly more business-oriented lens, rideshare drivers might be more likely to make decisions based on total cost of ownership. More broadly, public investments in electrified transportation infrastructure may be too focused on personal EVs and not focused enough on support for EV fleets, which can expand access to EVs and move more people around in a sustainable manner. Ridesharing, delivery, and other fleets may soon be filled with EVs – potentially automated ones – and investments and infrastructure are needed to support them.

National and state level EV mandates and incentives could drive serious investment, innovation, and experimentation. In the United States, a lot of the efforts to electrify vehicles have been state-driven, in terms of both incentives and requirements related to air quality and GHG emissions. California's governor, for instance, issued an executive order in 2020 to phase out the sale of internal combustion engine vehicles, which seems extraordinary in the United States but is similar to actions already taken in Europe and China. There has also been U.S. federal support for EVs, such as through EV tax credits, but the credits, while impactful, are not useful to everyone, as they require tax liability. More is needed. For example, the federal renewable fuel standard could be modified to include credits for electrification, more like the Oregon and California low-carbon fuel standards.

Transit has been almost solely focused on commutes, but transit can do more to serve other transportation needs, especially now when commutes are fewer. Public-private partnerships, such as to enable automated-vehicle ride-sharing, may be a key way to create an expanded, better public transportation system, though public finance structures mostly do not allow such partnerships.

PUBLIC TRANSIT

EVs are essential, but they are not sufficient. Also important is reducing vehicle use and vehicle-miles traveled (VMT) while increasing accessibility – such as through pooled transport options. Public transit, however, is in bad shape, having seen huge drops in ridership due to the COVID crisis. Transit has also been defunded and starved for so long that it is not serving the needs that it could be. In some communities, transit plays fundamental transport, economic, and public service functions, but lots of transit operators are disappearing in smaller cities, and rural transit has been hit even harder. More operators will disappear in the next couple of years unless there is a huge public transit bailout.

On average, transit serves only a tiny percentage of trips in the United States, which means there are huge portions of the population it is failing to serve – even within target populations such those with low income or physical disabilities. More time, effort, and money need to be spent making transit available to the vast majority of the population. The deal struck in the early 1980s to fund transit at a small fraction of the amount spent on highways should be revisited.

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FREIGHT TRANSPORTATION

There tends to be a lot of media and policy focus on passenger vehicles, but they only account for about a quarter of transportation demand. Freight transportation, whether via air, ship, rail, or truck, is a big portion of the rest. The scope for displacement of oil and fossil fuel consumption there may be larger than is commonly assumed. Decarbonizing heavy-duty transport can drive GHG reductions, air quality improvements, and public health gains across the globe, including in developing nations and pollution-burdened communities, but getting mass adoption will require vehicle and fuel solutions that are less costly than current options.

The trucking industry is embracing electrification, and fleets are analyzing several options, focusing generally on costs, emissions, and the supporting infrastructure needed. There are three main types of electric solutions coming forward: battery electric plug-in vehicles, hydrogen fuel cells, and electric long-haul trucks that use generators powered by renewable natural gas locally on the vehicle to recharge the batteries. The short-haul segment seems to be more amenable to a battery electric plug-in approach than long-haul; electrifying short-haul trucks is a great early opportunity to achieve both decarbonization and air quality benefits, particularly for communities around ports. There is a lot that can be done with today's electrification technologies that would make a big difference, but there are also some infrastructure and process challenges. For example, plug-in electric trucks could draw significant amounts of power, so even a few electric trucks in a fleet could strain or break local grid capacity in some places. Fleets are also used to fuel certainty, so now there are companies working to create the equivalent of power purchase agreements (PPAs) for fleet recharging.

Even after electrifying everything feasible in trucking, there will likely be emissions remaining from applications less amenable to electrification. Hydrogen could be an option, but lifecycle emissions have to be considered. Hydrogen burns cleanly, but its production can lead to significant emissions depending on how it is made, so the hydrogen used would have to be green hydrogen (from renewables), blue hydrogen (from natural gas with CCS), or some other kind of decarbonized hydrogen. As with electrifying short-haul trucks, these decarbonized fuels could provide both GHG benefits and air quality benefits, especially in freight corridors that tend to have large populations in disadvantaged communities. In addition, there are emission reductions to be achieved from efficiency gains, including light-weighting and systems efficiencies, which should be pursued in parallel with fuel-switching.

Rail is also important. Part of the focus in rail is on what powers it – and many rail lines are already electrified in some countries – but a bigger focus seems to be on the potential to displace road transport. There is a vast infrastructure of rail that is largely disused or under-utilized, and it would not take much to bring it back and move transport off the road. In India, for example, there is a drive to move transport from diesel trucks to rail, and there is a live conversation in France too. The UK is seeing a lot of pressure to move freight from road to rail as well, but the UK has a capacity problem in that a lot of lines are saturated with passenger traffic, limiting the ability to bring in more freight line connectivity.

As with electrifying short-haul trucks, these decarbonized fuels could provide both GHG benefits and air quality benefits, especially in freight corridors that tend to have large populations in disadvantaged communities.

Unlike trucks and trains, the marine shipping sector tends to be somewhat out of sight for many people, but it is a source of significant emissions. Ships use a very simple powertrain, so there is a huge opportunity for decarbonization. Battery electric approaches will help in the smallest vessels, such as those serving coastal routes, and that is where national governments should start their efforts to decarbonize shipping. (Ships could also use electricity to address local air quality problems in port cities, and every port could be putting ships on shore power; West Coast ports are leading on that in the United States.) For deep sea vessels, marine diesel engines are very versatile and can switch to methanol, methane, ethane, ammonia, or other fuels relatively easily. Ammonia seems to be the ideal fuel for shipping, as it is an energy-dense way of storing hydrogen and is significantly cheaper than synthetic hydrocarbons. Even super-cheap ammonia, however, is more expensive than the heavy fuel oils – the residual waste products of refining – that ships currently use. Investment therefore is not currently flowing into the sector's fuel supply chains or fleets because it is hard to make the business case, and making shipping more expensive hinders the ability of developing countries to grow export-led economies. There has also been little pressure thus far from shipping customers seeking to reduce their Scope 3 emissions. There are starting to be more efforts, such as by commodity brokers and movers, to monitor every shipment's carbon intensity on a more granular level, but the container fleet's customers are not yet asking those questions, nor are the structures in place to have data transparency. Interestingly, there is an opportunity in some fleets for wind assistance – taking renewable energy directly to assist propulsion, like ships used to be moved – and some big owners and operators have achieved significant fuel savings by using wind on specific routes.

There are synergies to be had across the forms of transport and beyond, such as through electrification. Ports, for instance, are multimodal and have both industry and transport, and short-haul trucks, ships, warehouses, cranes, machinery, rail heads, and more could all benefit from electrification – though that adds up to a lot of electrical demand and requires significant grid infrastructure. There could also be synergies with the rest of the energy system, such as demand response between transport vehicles or an electrified warehouse and the electricity grid. The shift to clean transportation technologies is so much in its infancy that these kinds of potential synergies sometimes get overlooked.

Both private- and public-sector actions are needed to accelerate the decarbonization of transport. On the private side, corporate net-zero commitments could be a driver for decarbonizing transportation, but more precision may be needed about what the commitments mean (e.g., whether they include offsets). More precise commitments could send signals to investors in fleets to prepare to seize the market opportunities presented by that net-zero corporate demand. First movers willing to pay a near-term premium could hopefully drive some cost reductions, and policymakers could put incentives in place to further help drive down any cost premium. Government subsidies for new vehicles and alternative fuel solutions are a huge help, accelerating the willingness of fleets to take on new projects. Government financial commitments in stimulus packages can advance innovation and investment in new fuels, and in the longer term, price signals, fuel standards, and requirements on fuels can help drive decarbonization in the space.

If governments want any of the jobs and exports in zero-carbon transportation, they need to be stimulating their nascent and innovative companies very soon in order to compete with China, which can be – and has been – a global leader. China is actively decarbonizing its domestic transportation, including electrifying bus fleets in many cities, electrifying some trucking, and generally implementing aggressive electrification policies at provincial and city levels. It is already exporting electric buses and other zero-emission transit. China also builds a lot of ships and is leading on shore power and electrified ports. China will play a huge role in driving technology and reducing costs.

NON-TAILPIPE EMISSIONS

Tailpipes are not the only contribution that transport makes to climate change. Transportation is also one of the largest users of GHG-intensive materials, used in the manufacture of vehicles and the creation of materials (e.g., cement) for roadbuilding. For a gasoline car, a non-trivial percentage of lifecycle emissions come from its manufacture, and that percentage is even higher for EVs. These embedded emissions will become a bigger part of transportation's emissions contributions as progress is made on tailpipes. Of course, transportation will not be decarbonizing in a vacuum. Much of the economy will be decarbonizing as well, including cement manufacturing, vehicle manufacturing, and other industrial processes, which means a lot of the carbon intensity embedded in vehicles and transportation infrastructure will also be reduced dramatically over time. Still, when thinking about new transportation systems and infrastructure, it is important to think about how to reduce the impacts of the system more broadly, including materials.

One approach is to reduce the impetus for constant roadway construction. When the things people need are far away, the compensating approach is to make roadways super-fast, widen roads, and so forth. Many current land use codes were created almost a century ago and should be updated; there is probably a need for another very strong federal guidance on land use to help create communities so the things people need are closer to where they live. That would reduce the need for as many materials in the first place.

There may likewise be a need to move beyond the legacy transportation system and rethink it to serve more people with better accessibility and fewer vehicles.

There may likewise be a need to move beyond the legacy transportation system and rethink it to serve more people with better accessibility and fewer vehicles. For example, shifting mobility more to a centrally owned fleet model rather than an individually owned vehicle model could mean significantly fewer cars are needed to deliver mobility services. Human behaviors are a challenge, though. Behavioral science has shown that people in the United States are really invested in their cars, which is the cultural milieu they were born into, unlike in Europe, where cars occupy a less central role. Even as wedded to their cars as Americans are, that behavior is also structurally reinforced by systems and infrastructure that make it unsafe or infeasible to get places any other way. COVID, however, may have shifted some cultural expectations and experiences. It is possible that people's current expectations of being able to walk out of their homes and navigate local streets without fears of traffic or having to avoid cars may persist. During the pandemic, ride-share bike and scooter usage has also increased substantially, largely because people want ways to travel that do not involve coming into contact with anyone.

The transportation system has other significant externalities as well. The transportation system exacerbates or causes stormwater runoff, loss of green space, habitat loss, public health impacts, roadway deaths, reduced physical activity, and air pollution from asphalt. The car-centric system also leads to unequal access to opportunity; it is expensive to have one car per person of driving age. Existing transportation infrastructure creates physical barriers to things too;

many highways, in fact, were built decades ago with the express purpose of cutting off minority communities, and those barriers are still in place. These inequities could remain in place after converting vehicles or could be addressed by pursuing decarbonization strategies that yield co-benefits. The changes wrought by the pandemic and its eventual aftermath may create an opportunity for a new course forward here too. Between potential stimulus legislation, transportation reauthorizations, and climate legislation, there is a great opportunity to change direction; passing just another typical surface transportation bill would be a setback and would miss the opportunity to reduce greenhouse gas emissions while reducing household transportation costs and improving equitable access, public health, and quality of life.

INDUSTRY

Heavy industry is a huge source of global GHG emissions. It is sometimes described as "hard to decarbonize" because it is very reliant on fossil fuels to generate high-temperature heat and may not be amenable to an "electrify everything" strategy, but there is lots of activity suggesting the world is on a path to achieve industrial decarbonization in the long term.

INDUSTRIAL HEAT

Industry players are among the hundreds of companies that have signed on to achieve science-based emission reduction targets. Heat accounts for about half of industrial emissions, with the other half from processes. Production of heat for industry accounts for more global emissions than cars and planes combined. Fossil fuels are very good at producing heat for industry; they burn at high temperatures, are reliable, and provide continuous operations. Replacing that type of functionality is not easy.

Production of heat for industry accounts for more global emissions than cars and planes combined.

The decarbonization challenge is made more acute because industrial facilities have long-lived capital stock that lasts decades. Many industrial products also trade globally on very thin margins, so small price increases to achieve decarbonization may mean products cease to be competitive. (The low margins also mean it will have to fall to governments to invest in the needed RD&D.) Several industries are considered strategic by their national governments, further adding to concerns about additional costs affecting competitiveness.

Hydrogen can substitute for fossil fuels in many processes, but it needs to be zero-carbon hydrogen in order to help with decarbonization. Hydrogen is currently mostly produced from natural gas, so CCUS will be needed to make that hydrogen a low-carbon option while waiting for costs for green hydrogen to come down. Zero-carbon hydrogen is currently pretty expensive, but it may be possible to produce clean hydrogen quite cheaply by using hydrocarbon fuels others do not want, stripping the hydrogen off, and putting the carbon back in the ground.

Hydrogen would also require huge investments in infrastructure, starting now, and it is not clear that markets are set up to incentivize that kind of investment. The question of whether it is cheaper to repurpose existing infrastructure (e.g., pipelines) or just reuse the rights of way really comes down to the distance the hydrogen has to be moved, the level of blending involved, and materials compatibility. Hydrogen can be blended with methane up to some level without bad metallurgical effects, but as blending levels get higher, there are concerns about the metal, coatings, and seals. Burner tips and other end-use equipment would also have to be changed.

All that said, clean hydrogen is showing signs of beginning to scale up. The EU's pledge to have 40 GW of electrolyzer capacity by 2030 could, by itself, lead to substantial cost declines that could, in conjunction with a robust carbon price, make green hydrogen cost-competitive with the cheapest fossil fuels for steel, cement, and glass-making. Incentives for hydrogen will be important for years, but investment is starting to move, faster than many thought possible even a couple of years ago, and voracious economies are out there that want to play in the hydrogen space. Many developing countries have advantages over developed countries in their potential to produce cheap zero-carbon hydrogen. The Middle East, for instance, is proving that it can ramp up and export hydrogen as ammonia quickly and cheaply.

Other technologies worth pursuing (and where more RD&D is needed) to decarbonize industrial heat include biomass, electrification, and CCUS. Biomass also burns at high temperatures, and there could be good opportunities there. Electrification could be an answer in several forms, including via electric arc furnaces. CCUS would be an approach not based on fuel substitution and would interfere less with core industrial processes by being added on at the back. In addition, advanced nuclear reactor systems could produce heat for high-temperature industrial processes (or to make zero-carbon hydrogen).

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STEEL

The two most promising opportunities for steel decarbonization may be electrification of steel production and using low-cost, low-emission hydrogen as a reductant. CCUS may also play a role but would leave some remaining emissions that cannot be captured.

Recycling had seemed like a key strategy, but modeling has suggested that there is a lack of recyclable material to use. Most steel is already recycled today, and the rest is locked into buildings that are not being taken down any time soon. There are both quantity and quality issues concerning recycling. The quality issues are very serious; if changes are not made in how steel recycling systems are managed, scrap steel will start being thrown in landfills in the 2030s. Recycling technologies that allow retention of more quality in recycled steel, such as by sorting scrap steel by current alloy more quickly and efficiently, are really important and need more attention.

Substitution could be another option for reducing emissions from steel, such as replacing some steel with cross-laminated timber. Some foresters suggest that, in terms of wood availability, a big push on cross-laminated timber would only be possible in North America and perhaps Scandinavia; in the rest of the world, the trees are more valuable in the ground. In places where the wood is available, cross-laminated timber could replace steel used structurally in buildings, which could be a small but substantial percentage of steel; it is not the whole solution, but it could play a role. In addition, in the United States, many forested lands are privately held and are being cut down and moved to other uses, so incentives to keep or increase the lands held in a forested condition would also help remove more carbon from the atmosphere and store it in wood in buildings. Cross-laminated timber thus opens up the opportunity to avoid emitting some of the GHGs from making steel, stores absorbed carbon in durable goods, and creates an incentive to keep lands forested.

EFFICIENCY

Industrial processing involves lots of wasted heat, resources, and electricity, so efficiency also has a big role to play in reducing industrial emissions. Separations, for instance, consume substantial amounts of energy that could be somewhat displaced with more efficient technologies. In chemicals manufacturing, a large part of the cost is the separation process – mostly evaporation and distillation using thermal energy – that goes into purifying and making the components that react together to make whatever the final product is.

Efficiency is low-hanging fruit. Spending less on energy is good business. Companies can try to change processes, make more product with existing assets, and perhaps find new ways to produce and use cheap renewable electricity on-site. There are significant hurdles, though. Manufacturers are resistant to changing or replacing fully depreciated assets, and there is aversion to changing established processes. A plant manager will not get fired for processes that have the same energy intensity as has been the case for the past century, but a manager might get fired for trying a new process that hurts product quality, reduces product volumes, or makes production lines go down. Industrial heat pumps are a good example of this risk aversion. Heat pumps are a great way to reduce energy and switch to electricity, and they are usually better at maintaining the quality of temperature required, but industrial facilities are hesitant to include them. Given capital constraints, heat pumps' upfront expense, and concerns about affecting the quality of output, industrial facilities buy heat pumps on special procurement as pilot projects, and they also buy backup equipment, which makes the cost of the project even greater than it needed to be. The risk issues tied to product quality are huge barriers to uptake.

Industrial companies need top-down efficiency mandates like they have for safety. If they are not measuring efficiency, they do not know how they are doing or what targets to set for improvement.

Both government and private investment have a role to play in addressing inefficiency, and incentives and structures to promote fuel-switching are important. It is clear that such efforts can make a big difference. For example, there are more efficient chemical plants in Europe than in the United States, and more efficient ones in Asia than in Europe. More attention and money need to be directed to measuring and identifying efficiency improvements, including process intensification. Industrial companies need top-down efficiency mandates like they have for safety. If they are not measuring efficiency, they do not know how they are doing or what targets to set for improvement.

ECONOMICS & MARKET CREATION

The transition to a low-carbon industrial sector should be very affordable since, from a macroeconomic perspective, the industrial activities that generate lots of GHGs are low value-added activities. While materials are responsible for most of the emissions involved in making finished goods, they are responsible for a tiny portion of the final price of a finished construction project – even concrete-intensive public works projects such as roads and bridges. Even if it turns out that abating cement emissions is very expensive, it would cause very small increases in the cost of a bridge and even smaller increases in the cost of a building.

While the transition is very affordable from a macroeconomic perspective, the upfront capital costs to decarbonize industry are non-trivial. Some projects are coming online, but CapEx is still a key barrier for adoption and trials of low-carbon production. There are also some very sticky social and political transitions to navigate; that piece may be harder than the technological and economic pieces. Industries tend to be very geographically concentrated; the people they hire and the revenues they generate tend to be concentrated in particular places, where the industries are the most important players in the local economy. More and more companies in heavy industry see emissions intensity as a potential barrier to future sales, but any policy that requires them to do their business in a different way will likely face significant resistance from local workers, industries, and politicians.

Because of this, as well as global competitiveness concerns, it may be more effective to focus on creating demand than on forcing facilities to comply with emission reduction requirements. It is critical to create market pull for commodities that have zero (or near-zero) emissions associated with their production. Social and political problems can still become obstacles as things scale up, but market pull mechanisms can sidestep some controversies.

There are many different possible options for market creation. Learning from the power sector, for example, among the most effective tools in getting renewable electricity commercialized in the first place were renewable portfolio standards and feed-in tariffs, which had very high associated prices and very low associated volumes, so the total financial outlay was not that large. Truly lead markets are much less threatening to existing producers given the small volumes. The goal is just to get new technologies or processes to market.

Demand signals for low-carbon products are still quite opaque, but public procurement policies could have significant market power. In the United States, substantial amounts of cement and steel are purchased with taxpayer dollars, and governments are major purchasers of other industrial products as well. The federal government does not do much direct construction, but a significant majority of construction at the state and local levels is done with some federal funding, and the federal government could tie strings to this funding. More broadly, procurement approaches could include low-carbon purchase mandates, contracts for differences, long-term offtake agreements, or other measures – though these may require legislative changes, as federal codes currently require procured products to be the lowest cost. In addition, standards for products could help make clear what counts as low-carbon, and tradable markets to price low-carbon products can also help, such as a green aluminum spot market. Other public policies that could provide much needed support for decarbonization and for products with lower lifecycle emissions include subsidies for the production of low-carbon heat, carbon prices, border carbon adjustments, and investments in RD&D to bring down costs and perceived risks to quality and reliability. There also need to be senior officials in the U.S. government whose job it is to think about the future of U.S. manufacturing, which there are not at the moment. One should not underestimate the political challenges of getting any of these types of policies adopted.

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Market-pull approaches are not limited to the public sector. Private-sector procurement can have significant impacts as well, such as through high-leverage goods that use lots of steel (e.g., cars, appliances). Actors such as large corporations and universities also do a lot of construction. The clean energy industry itself could play a bigger role in creating demand for low-carbon commodities (e.g., steel for solar racking systems) to lower the overall lifecycle impacts of clean energy projects; off-takers can add questions to PPA requests asking developers about how they ensured the lowest-carbon materials were used.

INDUSTRIAL DECARBONIZATION OUTSIDE THE UNITED STATES

What happens in the United States in terms of industrial decarbonization will really matter most if it is transferred to Chinese industrial activity or is developed in combination with Chinese producers. Decarbonizing industry in China is essential to addressing climate change, as a huge percentage of China's emissions are industrial, particularly if one includes emissions from electricity consumed at industrial facilities. China produced more cement in the past decade than the United States did in the entire 20th century, and China's steel production is about half of the global total. On the other hand, Chinese paper manufacturers are already implementing a lot of efficiency improvements that have not even been considered yet in the United States, and industrial facilities in China tend to be newer, more centralized, and more compact, thus requiring less steel and cement.

India is also ramping up fast in these industries. India is relatively resource-poor in industrial raw materials, which should make it easier to argue that it should be relying on its abundant sunlight instead of importing metallurgical coal. India, however, also has hundreds of millions of people that lack modern housing, access to modern transportation, and so forth, so it is under cost pressures unlike those in many other large markets.

Europe is pursuing market-pull approaches to advance industrial decarbonization, particularly with regard to hydrogen. Europe is moving away from feed-in tariffs to contracts for differences, with subsidies likely covering the difference between the cost of abatement in a process that uses hydrogen and the price of allowances in the EU Emissions Trading Scheme (if the EU ETS price is lower). Portugal is going further and is doing contracts for differences based on the comparison to natural gas spot prices. There are industrial decarbonization pilot projects coming online in Europe to test new production processes, as well as more funding for hydrogen and other clean energy efforts in Europe's COVID stimulus packages.

CARBON DIOXIDE REMOVAL & UTILIZATION

Carbon dioxide emissions are a form of trash, but the dump is the atmosphere. Billions are spent every year for trash to be taken from people's homes (e.g., landfills, recycling), and billions more are spent to take and treat wastewater (including recycling some and sequestering some). It should be possible to pay to clean up gaseous CO2 waste as well, creating jobs by removing it from the atmosphere (or the oceans) and/or diverting it for productive use. Conversations about carbon dioxide removal and utilization that were merely conceptual a year or two ago are now much more concrete and material.

CARBON DIOXIDE REMOVAL

It has only been relatively recently that the concept of "net zero" came into prominence, and it is not clear that all who use the term focus on what it implies. It is likely to be carbon dioxide removal (CDR) that puts the "net" into the concept. Simply put, to achieve net zero, any emissions of any greenhouse gas by any source must be balanced by removals, otherwise the emissions keep adding to atmospheric stocks.

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Removals are not the same as emission reductions or avoided emissions growth, even though the terms sometimes get conflated. The latter terms suggest that some amount is being emitted (or is projected to be) by some source, and after some change, that amount is less. Removal, in contrast, involves actually taking carbon dioxide out of the air and the oceans. Like offsets, though, verification of CDR projects is important to figure out, to determine what projects are truly net-negative and sustainable over decades or centuries.

The pace and scale of CDR needed are daunting. Removal needs to go from thousands of tons today to billions. A best guess is that 10 billion tons a year of removals will be needed by mid-century, but it could be 5 billion or 20 billion depending on the emissions trajectory and the aggressiveness of other actions taken. Among some in the climate world, there can be some contention around CDR and the risk of it undercutting the drive for strong mitigation, but CDR is not a substitute for the rest of mitigation. All of it is needed. To hit a 1.5°C target, for instance, global emissions have to be cut in half in 10 years in addition to doing CDR. Still, any delay or failure on any other mitigation front will require more CDR. It is simply about tons and time.

CDR can take various forms, but the main ones include nature-based solutions, bioenergy with carbon capture and storage (BECCS), and direct air capture (DAC).

Nature-based solutions involve taking CO2 out of the air and putting it into biomass stocks, whether soils, forests, or something else. The most valuable pathway may be taking marginal or degraded lands and putting managed forests on them. (These are managed ecosystem approaches, not just planting trees and walking away.) In the near term, there is a need to continue to invest in nature-based solutions – if nothing else as ecosystem life support – while getting higher-priced, more sophisticated, more ironclad engineered solutions up and running and affordable. It is important to recognize, though, that pursuing the laudable and essential goals of biodiversity, sustainability, ecosystem services, and natural preservation is not inherently the same as pursuing the goal of pulling carbon dioxide out of the air and oceans. For instance, some literature suggests that working forests that produce products sequester more carbon dioxide then forests left alone.

While the biosphere can certainly absorb some of the excess carbon in the atmosphere, humanity has put way more into the atmosphere than the biosphere can take, so some of what is removed will have to go back into the geosphere. One CDR approach that links all three – the atmosphere, the biosphere, and the geosphere – is BECCS, in which biomass that takes CO_2 from the air is combusted in power plants that have technologies that capture the emitted CO_2, which is then sequestered underground to achieve negative emissions. BECCS relies on carbon capture technology (which already exists but needs to be substantially scaled up), sustainable sources of biomass, and carbon transport and storage infrastructure. The cost of BECCS – which can be offset somewhat by the electricity generated – depends on where it is situated; a BECCS power station in the Gulf Coast of the United States, where there is lots of wood residue and where CO2 pipelines are already in place, would have much lower costs than one located in a place that lacked those things.

CDR can take various forms, but the main ones include nature-based solutions, bioenergy with carbon capture and storage (BECCS), and direct air capture (DAC).

Direct air capture, which skips the biosphere entirely, is an engineered solution that, as its name suggests, directly captures CO_2 from the air. While DAC is still in its early days, it is starting to seem like a more viable option. DAC is currently the most expensive version of CDR, though it still costs less than what has been paid for some other mitigation efforts, such as sustainable aviation fuels. The DAC numbers are also going to come down. As DAC's price drops, it puts a lid on the cost of compliance to achieve ambitious net-zero targets. Most integrated assessment models and models of the energy economy that are used to evaluate different policy approaches to decarbonization do not include DAC as an option, but there are efforts underway to begin to better incorporate DAC, which will have implications for what the costs of different policies are projected to be. Having a DAC removal cost number creates a fallback maximum price.

People are really only beginning to think about CDR in a serious way, and there is a huge amount to do on an innovation and research agenda. For instance, there is a need for better science around monitoring nature-based solutions, especially soil carbon. The U.S. Department of Energy (DOE), which historically has funded billions for RD&D on point-source capture, has invested little in DAC, but DOE's attention to and spending on DAC has increased recently, which has helped spur some early movement on DAC technology demonstrations. There is a need to put significantly more money into this, though. There are cheap, creative, potentially effective solutions out there for air and ocean carbon removal that were not even being discussed a year ago.

While funding for basic and applied science is needed, it is also critically important to get capital for putting up CDR plants to enable learning-by-doing and cost reductions. The government needs to step up, announce ambitious plans, and provide a catalyzing leadership role for corporations and other investors to also step up. Early in CDR development, there is a need for incentives such as tax credits. The 45Q tax credit in the United States offers up to $50/ton for DAC and sequestration, but improvements in 45Q are needed (e.g., to provide more time to put a plant up). Credits under California's Low Carbon Fuel Standard, trading around $200/ton, can also help support DAC (and could be stacked with 45Q), and if the federal government converted the renewable fuel standard to something more like a low-carbon fuel standard, it would go a long way to getting more CDR in action. Tradeable performance standards could provide important support if CDR is a compliance option in those trading systems. It is hard to finance against tradable performance standard values, though, as there is no certainty that any given price level will continue; some backstop to the value, such as a contract for differences, would be very useful. Contracts for differences, which worked well for offshore wind in the UK, provide long-term revenue assurance that gives the private sector comfort to put capital in. DOE support and loan guarantees could also be of help; a number of DAC technologies are fairly modular, so with millions or tens of millions of dollars, it is possible to get a demonstration plant up and running.

To scale, though, will require a huge amount of capital and support. When considering that perhaps 1,000 DAC plants will be needed in the United States alone by mid-century, tax credits and such will be grossly inadequate. The government will need a procurement program for CDR and sequestration that scales up over decades; CDR ultimately provides a pure public good, and governments will have to buy it. Governments are always market leaders. Governments were the first purchasers of solar, fuel cells, LEDs, and more, and government procurement of CDR will be just as vital. The government should buy CDR and commit to doubling purchased volumes on some schedule.

Contracts for differences, which worked well for offshore wind in the UK, provide long-term revenue assurance that gives the private sector comfort to put capital in.

Capital for a huge scale-up of CDR can also come from investors and large corporates. While voluntary offset markets are unlikely to provide much support for CDR – as offsets tend to go to things that are already at scale and cheap, and emerging technologies such as CDR are neither – corporations can bring a range of other levers to bear on CDR, including funding for early-stage ventures and procurement of carbon removal credits. A shared-risk approach could also work, replicating around DAC something like the renewable energy buyers groups' fractional investment model. Just as corporate purchasers got a lot of renewables developed, the early movers in CDR can establish practices for other corporations to follow. Indeed, corporate support for CDR has ramped up over the past year, with some important commitments to eliminate past emissions and with sizable investments that are providing support to the field. By paying a premium, these corporate leaders are moving CDR technologies forward and driving the price points down to more affordable levels. When DAC hits $100/ton, there will be many more corporates and others interested in CDR, but until then, there is a need for entities willing to finance and invest at some level of premium pricing.

CARBON UTILIZATION

Carbon dioxide captured from the atmosphere, from power plants, or from other point sources has the potential to be turned into market commodities. There is a lot of emerging technology for utilizing captured CO_2.

The technologies that are closest to scale include ones to produce methanol from captured CO2 and to embed captured CO_2 in curing cement. Some medium-term technologies include making carbon fibers, polymers, and consumer products from captured CO_2, thereby creating carbon-negative materials and products to market and sell. Captured CO_2 can also be used to make artificial aggregates. Concrete aggregates are one of the only things on earth used in billions of tons per year, and the reactions are one of the few that CO_2 will do at atmospheric temperatures and pressures, but artificial aggregates made from CO_2 face a range of challenges, including cost-competitiveness.

The technologies that are furthest from scale, such as making liquid fuels from captured CO_2, are also the ones that would have the most impact on addressing climate change. Fuels are the largest source of CO_2 emissions now, and making diesel or jet fuel from captured CO_2 instead of from hydrocarbons pulled from the ground could enable carbon-neutral transport. Such fuels may have big competitors. Ammonia, for instance, already has global distribution capacity (because it is used for fertilizer and other things), involves reasonable temperatures and pressures, has good density, is easily gasified, and can be used in regular engines. Hydrogen, likewise, can be a competitor for some industrial and transport applications. Many fuels are needed across the economy, though, and fuels are the big target for carbon utilization. Many companies are looking into it.

Building a CO_2 utilization company in a capital-constrained world is a challenge, though. Companies are learning from prior waves of clean-tech firms and are starting small, getting some revenues early to support the companies, and then moving to larger markets. So some companies are starting with things like carbon fiber before trying to tackle fuels. Enhanced oil recovery (EOR), which is a market with a high price and lots of CO_2 demand, has been the main way to get revenues from carbon utilization so far, but in the climate advocacy and climate philanthropy worlds, EOR causes some heartburn. There are also niche markets, such as CO_2 for beer, but scaling requires substantial market uptake. There is a need to find other ways to drive down the costs of carbon utilization.

One approach is to reduce the costs of manufacturing. For instance, for CO_2 utilization companies, CO_2 is often not the most expensive part. Other resources are needed to utilize the CO_2, whether heat, electricity, hydrogen, alkaline material, or something else; those resources need to come down in cost too. Companies that need electricity and can operate intermittently could perhaps try to find opportunities to use curtailed renewables generation, which could bring down the cost of manufacturing. Some are also exploring trying to utilize existing manufacturing plants that are operating at reduced capacity, rather than trying to build an entirely new manufacturing plant; there could be opportunities for public-private partnerships to allow for new and emerging technologies to leverage existing manufacturing spaces.

As with so many other technologies, government procurement could also play a powerful role in advancing carbon utilization.

Additional demand and revenues could also help. CO_2 utilization companies would benefit from companies that were looking to address Scope 3 emissions and willing to pay for captured CO_2. Part of the pitch from companies looking to turn CO_2 into building materials, for instance, has been that procuring their materials will help companies on Scope 3. Some companies are currently paying good prices per ton of CO_2, but those companies are mostly looking in a Scope 1 sense; Scope 3 would open larger potential investment streams for companies and technologies. Scope 3 emissions accounting, however, is a mess and a potential obstacle to carbon utilization. Making a product with CO_2 currently adds to Scope 3 burdens, and companies do not want that. Scope 3 needs to be modernized and rationalized around how to think about carbon negativity and carbon neutrality.

Policy is another key way to support carbon utilization. CO_2 utilization at scale will take alignment between technologies, markets, and policies. The shale transformation can be instructive. The technologies (e.g., horizontal drilling, chemical additives) had finally arrived, the policies (e.g., decades-long R&D support, state regulation) were clear and stable, and the market around 2008 (e.g., high gas prices) sent signals to drill. If there is alignment, rapid transformation is possible. That alignment is currently missing on CO_2. The technologies are mostly there, but markets are confused, and policy is not clear. As was the case with shale, solar, and many other energy technologies, multiple policy levers are needed.

For example, carbon utilization companies can be supported by R&D grants (with strong technical review panels that investors can trust). For first-of-a-kind deployment, public-private partnerships and grants can be valuable, such as Europe's new grants under the Green Deal for CO_2-to-fuels projects to show the technologies can work at scale; that kind of deployment can de-risk the technologies from an investor standpoint. For second and later deployments, other types of financing could come in.

As with CDR, the federal 45Q credit and California's Low-Carbon Fuel Standard also provide some push but will not quite be sufficient by themselves. Post-COVID recovery measures could also provide significant support. Investments in DAC plants could create thousands of jobs, existing CO_2 pipelines could be repurposed, and workers in companies conducting layoffs could get paid to put CO_2 back into the ground or into airplane tanks.

As with so many other technologies, government procurement could also play a powerful role in advancing carbon utilization. This is true indirectly, as procurement standards for low-carbon-intensity goods and materials could spur the makers of those items to pursue carbon utilization, but it could also be true more directly. Government procurement for fuels made from captured CO_2, such as procurement by the military for aviation and naval applications, could be a significant demand lever that could buy down the cost of the technologies. In Europe, there seems to be more appetite to condition recovery on things like aviation procurement of DAC fuels; France, for instance, is making low-carbon jet fuels part of its bailout conditions.

BUILDINGS, NEIGHBORHOODS, & CITIES

Buildings, neighborhoods, and cities are where the various sectoral elements come together and thus are a core aspect of the deep decarbonization challenge.

BUILDINGS

Buildings account for a large amount of greenhouse gas emissions, power consumption, peak power demand, and thermal energy consumption. To decarbonize buildings, the first step involves advancing energy efficiency. Through measures such as building performance standards, most buildings could cut load by almost half.

Electrification is another core strategy to promote building decarbonization. There has been some progress on this front, though some electrification technologies that are cost-competitive now, such as heat pumps, are not being installed due to behavioral and regulatory hurdles. Utilities might be able to accelerate deployment of technologies such as heat pumps, given their access to low-cost capital, but there is a question of whether customers would accept utilities owning the equipment in their homes. Some Americans may not want that, but many may not care; indeed, a fast-growing part of the residential HVAC market is people renting their systems. Owning, renting, and energy as a service could all be useful models to advance building electrification.

Neighborhoods and cities are currently built for cars instead of people. Daily lives are centered around cars and commutes; this is damaging to infrastructure and society and fails to capture externalities related to congestion, time, health, and carbon.

To advance electrification at scale, buildings need to become more digitized. Buildings need to go from being dead, heavy load to being agile, flexible grid assets. That will require new government action on regulations and standards. Appliances and equipment should be required to be smart-ready. Markets need to be redesigned to level the playing field for grid-edge assets and batteries. There is also a need for uniform codes around cybersecurity and data privacy, or else it will be impossible to digitize buildings efficiently.

NEIGHBORHOODS & CITIES

Scaling up from buildings, neighborhoods and cities are where people live, work, and play. Neighborhoods and cities are currently built for cars instead of people. Daily lives are centered around cars and commutes; this is damaging to infrastructure and society and fails to capture externalities related to congestion, time, health, and carbon. Because of COVID, though, people are working more from home, riding bikes and scooters more, dining outdoors more, and spending more time in their neighborhoods. Supporting vibrant neighborhoods – such as ones where people can work, play, and grow within a 15-minute walk or bike of where they live – can reduce the need to move people and stuff around so much. There is an opportunity now to reimagine neighborhoods and cities to be better for people and the planet.

The concept of "smart cities" and "smart communities" is one such reimagining effort. The concept has evolved from a primary focus on technology to a broader focus on modernizing infrastructure while harnessing technology. A smart and connected community is one that leverages technology to modernize its digital, physical, and social infrastructure in an integrated manner; the social infrastructure, in particular, has been lagging far behind. The goal of a smart city is to make the delivery of essential services more efficient, sustainable, cost-effective, secure, equitable, reliable, and exciting.

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There is a lot happening on the technological front, with rapid improvements in hardware and software. Power electronics, sensors, telecommunications (e.g., 5G), smart LED street lights, building energy management systems, and more will change cities and energy systems. Partnerships between cities and utilities, as well as others (e.g., local military bases), can advance efforts to convert existing infrastructure to smarter, better, cleaner, more resilient, more secure technologies. Some utilities, for instance, are undergoing digital transformations, digitizing everything from operations to the back office, installing large numbers of sensors that are streaming huge amounts of data, and partnering to develop apps to make that data useful and actionable. Deployment of new technologies requires finding the relevant value propositions for the deploying companies, as well as making sure they are deployed equitably.

Progress on smart cities around the world has been substantial over the past few years, but smart city development over the next few has to be faster and accomplish more, given the urgency to change how buildings are used, how people and goods are transported, how energy is used and produced, and more. States and cities do not have the funding, however, to retrofit lots of infrastructure. Creating smart cities in the time of COVID, economic contraction, civil and racial unrest, climate impacts, cyber intrusions, and other disruptions will require leadership, urgency, and creativity, especially regarding financing. There is a need for the equivalent of a federal mini Marshall Plan for cities to integrate telecommunications, advanced mobility, building design, and much more in a way that is not being done thoughtfully now. Countries that have alignment from the national level to the local level on smart city concepts can move faster and be more impactful.

INFRASTRUCTURE & FINANCE

Achieving economy-wide decarbonization will require building a lot of infrastructure, but building infrastructure is hard to do. Procedural changes and enhanced finance will be necessary.

BUILDING INFRASTRUCTURE

The United States does not have enough infrastructure to achieve deep decarbonization. Electrification, for instance, is a major decarbonization strategy. For light-duty vehicles or buildings, electrification will lead to new load that for the most part is closely geographically aligned with existing load, though there will still be a need for more transmission lines, charging stations, and so forth. Other types of electrification, such as in heavy industry or freight transport, could create enormous loads in places that currently do not have anything approaching the transmission and distribution capacity needed to serve those loads. Electrifying just a single U.S. heavy industry sector (e.g., steel) would require a huge amount of electricity that the country currently lacks the infrastructure to handle. Huge new loads from electrification may require lots of new generation and storage, as well as a strong grid to move electrons around. The country is also grossly underprepared with regard to hydrogen pipelines, carbon dioxide pipelines, and other infrastructure that may be needed to decarbonize industry and other sectors.

While ambitious emission reduction targets may be technologically and economically possible to achieve, they may be procedurally impossible to achieve under current government regulatory and permitting structures without changes to enable the deployment of infrastructure. The non-technological political economy barriers are the main ones that will require focus and action if big infrastructure projects of any sort are to get built. The need to move through local, state, and federal regulatory processes quickly while also consulting and engaging with local affected communities will present challenges to moving quickly. There are tradeoffs between process and speed, but it is essential to get to 'yes' more quickly on projects; getting to 'no' quickly is also valuable. The years it takes to get permits and approvals to build things result in stranded capital and disengaged investors. The dollars developers rely on are not particularly patient, and in the competition for capital, faster projects will win out over slower ones. The faster that clean energy and other infrastructure needed for decarbonization can be deployed, the better, since CO_2 is cumulative. Moving faster is equivalent to additional gigatons of reductions.

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Some states have established permits by rule if new clean energy infrastructure is going to be built on an already built footprint (e.g., underutilized office parks). Some have tried to accelerate third-party review by pre-clearing a list of environmental engineering firms that project developers can choose; the firms would then iterate on the permit instead of the regulating agency, with the regulators only having a yes or no say, though if a firm gets three rejections from the regulators, it would be removed from the pre-qualified list. New York also has a groundbreaking new law to accelerate the siting of renewables – creating a new office for the siting process, establishing a one-year timeline from when an application is complete to when an agency has to make a decision, and providing certainty around mitigation measures so developers do not have to haggle with each local jurisdiction.

At the federal level, accelerating permitting has to happen through statute, though it may be harder to streamline and expedite permitting than some think. There is established case law on the National Environmental Policy Act (NEPA), and many points in the process that opponents of clean energy projects can use to delay and challenge – just as environmentalists have done for many oil and gas projects. NEPA allows for litigation to be an impediment to moving things forward quickly, and there will always be critics for any project. Reforms that ignore the need for a fully adjudicated final decision to occur rapidly will have little impact.

At various times in the recent past, Congress has – on a bipartisan basis – accelerated or waived NEPA for priorities such as forest management and border security. Something similar is needed on permitting for clean energy projects, while recognizing the value in the NEPA process from holistically weighing and comparing potential impacts and benefits. Some kind of new process is needed to allow decarbonization projects to move forward more quickly. Striking a deal to cut red tape may necessitate an agreement to provide expedited processes for projects with up-front performance metrics that demonstrably show them to be net better for the environment. There could be multiple lanes, and the projects with the biggest impact in driving toward net-zero emissions would be entitled to the fastest process.

Accelerating these permission processes is not about rolling back protections. Every project still has to comply fully with all federal, state, and local environmental, health, and safety laws (e.g., on clean air and water) throughout its design, construction, and operation.

The history of infrastructure development suggests that, regardless of sector, things get built when there is a will to build them. It is important, therefore, to create the broad-based will to build the infrastructure needed for deep decarbonization. In the United States, regulatory and permitting schemes are malleable, so the challenge is creating a new paradigm and persuading those involved in the regulatory system to shift the debate from whether a zero-carbon future is needed to how to get there.

FINANCE

Getting the needed decarbonization infrastructure built will require substantial public and private investment. There are trillions of dollars of equity and debt in North American energy capital markets (more equity than debt), with only a small percentage going to alternative energy; most goes to conventional energy and investor-owned utilities. It is mostly private capital – both debt and equity – that is funding the energy transition, supporting early-stage startup companies through late-stage mature companies.

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Venture capital (VC) generally gets involved in the risky, early stages. VC may not have the capital that other asset classes do, but it punches above its weight, as it is critical to providing the innovation that fuels the energy transition. When VCs invest, there are no (or minimal) revenues, no profits, and sometimes not even a product yet. The investment is made based on the potential future value from disrupting large markets, dislodging incumbents, and/or creating new markets. VCs expect to have several failures in their portfolios and to make up for them with some winners that will eventually be huge and provide enormous wealth creation for the long-term investors in the portfolio. VC helped mainstream technologies such as solar photovoltaics and electric vehicles (aided by supportive state and federal policies) and could have important continuing roles in advancing climate solutions in agriculture, natural gas replacements, and other areas.

The private infrastructure market, which is less well-structured but quite large, invests in the things that VCs help create. Private capital is adapting traditional project finance models to bring investment to the energy transition. State green banks and infrastructure banks have been quite successful in using public dollars to leverage significant amounts of private infrastructure capital in clean energy, through mechanisms such as credit enhancements and loan loss reserves that add extra layers of security and can bring private capital off the sidelines. Green banks do not compete with private capital; instead, they can target populations and sectors that have more limited access to capital and help organize public money to attract a lot of private dollars. There is not yet a U.S. Infrastructure or Green Bank.

Despite all the investment in clean energy over the past two decades, though, the share of energy supplied by clean resources globally has not increased; clean energy has increased, but so has use of everything else.

Once technologies are more proven, other investors come in, investing in long-term cash flows of operating assets. Renewable energy assets and infrastructure have proven to be resilient and are now an attractive asset class.

Green finance now seems to be available and cheap. In mature debt markets, green bonds have been oversubscribed, and the cost of capital has been driven even lower. Investors increasingly want to see environmental metrics adopted, and ratings agencies have been trying to adopt climate risk metrics. Huge money managers with lots of money in passive funds are now putting pressure on corporations and their boards for climate action. There are more and more signals in the capital markets, both proactive and reactive.

Investor-owned utilities can be thought of as a type of public-private partnership, bringing hundreds of billions of dollars of low-cost capital to the energy transition. There appears to be a direct correlation between strong regulatory constructs and having access to the deepest pools of low-cost capital. Regulated markets offer much lower costs of financing than competitive electricity markets (because earnings are more predictable), and incentive ratemaking could help utilities get better operating efficiencies by basing the rate of return on their performance and outcomes. When designed effectively, federal and state regulatory incentives can lead to substantial resource allocation by utilities, whether in transmission infrastructure, renewable energy supply, demand-side resources, or other efforts to upgrade assets and usher in new technologies that can drive decarbonization.

Policy matters in sending signals to invest in infrastructure. Tax credits, for instance, have been a driver of deployment in the United States, especially for wind and solar, and qualified opportunity zones open the door to lower costs of capital for projects that might not otherwise pencil out. A carbon price could provide a needed signal in the marketplace to invest appropriately to reduce greenhouse gas emissions across sectors.

Despite all the investment in clean energy over the past two decades, though, the share of energy supplied by clean resources globally has not increased; clean energy has increased, but so has use of everything else. It is therefore important to recognize that policy can also incentivize the retirement of infrastructure. Some states have looked to accelerate the closure of fossil fuel plants through mechanisms such as securitization that enable investors to recover investments. This is the equivalent of a debt financing vehicle, with surcharges added to bills that are lower than what the costs would be if the coal assets were retained. Such measures are not a panacea, as the asset owner foregoes earnings on what has not depreciated yet, and securitization might increase credit risk and financing costs.

DEPLOYMENT & INNOVATION

Tackling the climate crisis will involve a combination of deploying existing technologies at an unprecedented scale and rapidly developing nascent technologies. Both deployment and innovation are needed, at the same time.

DEPLOYING EXISTING TECHNOLOGIES

There is limited time to invent new things if they are to have an impact on avoiding the worst impacts of climate change. Given the urgency of the climate crisis, immediate early actions are needed to deploy technologies that are available now, while other technologies that will be needed in a clean energy future eventually come to fruition.

There are numerous technologies that already exist, at various degrees of maturity and scale, to promote decarbonization in the power, transportation, industry, and other sectors. There is too much incremental and siloed sectoral thinking, though, and more solutions to climate are possible by looking across sectors. For example, clean power and power-to-X (i.e., electrons to molecules) technologies, many of which already exist in some form, are critical to the energy transition in buildings, mobility, power, industry, and more. Likewise, co-generation approaches can break down sectoral silos and produce multiple outputs and thus multiple earnings streams.

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Hurdles to achieving deployment at scale are important to overcome. For example, it is worth thinking about the appropriate role of public utilities, governmental bodies, and other (potentially new) institutions in de-risking deployment of technologies such as nuclear and CCS. There has been a long discussion in the United States about nuclear waste and who is responsible for handling that risk profile, and a similar discussion could occur with regard to the underground injection of CO2. Utilities deploying carbon capture units may have expertise in capturing carbon but not in sequestering it. Deploying these technologies may require figuring out where responsibilities lie for these issues.

Business models can also affect whether and how quickly scale is achieved. For instance, a licensing model for newer zero-carbon technologies could enable others to build so the technologies can scale faster.

Scale can happen quickly, though. People have been indoctrinated with the idea that energy transitions are slow, but while that may have been true over the past 100+ years, this transition may not follow suit. It is easy to overestimate the changes in the clean energy transition over the next 2 years and to underestimate the changes in the next 10. EV deployment is an example. Utilities have done studies with consultants to estimate EV growth, see two years later that they are below where the study said they would be, and slow their efforts to prepare for EV deployment – when they should be moving faster because, over a slightly longer timeframe, the deployment is going to come. Likewise, while it took a century for the electricity industry to begin to get past the incandescent light bulb, the next 10 years in the electricity system will be unlike anything seen in past decades.

RESEARCH, DEVELOPMENT, & DEMONSTRATION

Some analyses suggest that half of the emission reductions needed to achieve net-zero will come from technologies that have not yet reached markets. Innovation is therefore critical to continue to develop nascent technologies to the point where clean energy financing can deploy them at scale. Both government and private capital are vital to developing a sufficiently robust research, development, and demonstration enterprise in the United States.

The national labs are already closely collaborating on existing technologies and innovations for the future clean energy system, including in renewables, storage, clean fossil, and nuclear. For example, new federal law is pushing advanced nuclear systems to the demonstration phase, with national lab locations serving as demonstration sites. The labs are also working on energy systems integration, including developing new platforms to bridge silos and figure out how to optimally design, develop, demonstrate, and deploy large numbers of technologies and devices across systems that work together in concert. The labs are partnering with the private sector too, including on innovation incubators to rapidly reduce technology risks and to promote commercial deployment. In addition, RD&D is underway by utilities, universities, and the national labs to understand the cybersecurity threat to existing and forthcoming infrastructure. Existing systems were not designed with cybersecurity threats in mind, but as the energy system evolves over the next few decades, it is possible that the system could use artificial intelligence and machine learning to self-protect and self-heal to be more resilient to attacks.

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More federal support for clean energy RD&D is needed, though. This is a competitive global landscape. China has nearly doubled its clean energy RD&D spending (in line with the Mission Innovation commitment), which means China will be spending about the same amount in absolute terms as the United States (which has increased spending by about 40% since 2015, thanks to strong support for clean energy RD&D in Congress). The EU has mandated hundreds of billions to be spent to reach its net-zero goals as part of its economic stimulus. South Korea is putting in more than $100 billion for clean energy deployment. The next Administration and Congress has the opportunity to pursue a new clean energy innovation mission – an area that has bipartisan support – with big increases in RD&D funding and re-engagement in Mission Innovation and other international innovation collaborations.

The significant ramp-up in U.S. clean energy RD&D funding needs to be mapped to critical decarbonization needs, including not just clean electricity generation (which tends to get most of the funding), but also relatively underfunded needs such as industrial decarbonization, CCUS, agricultural decarbonization, and carbon dioxide removal. Clean energy RD&D funding also needs to be distributed across research, development, and demonstration, as well as across federal agencies, national labs, companies, and universities. It would be good to spread those dollars across more areas of the country too, injecting public and then private capital both to capture more ideas and to build more regional innovation economies – including with equity and diversity metrics front of mind. To be effective, there needs to be not just RD&D, but also industrial policy for deploying it, bringing together regional manufacturing, education, finance, and the entire necessary innovation and deployment ecosystem. The history of U.S. national innovation missions in other fields suggests that to be durable, there is a need for bipartisan support that comes from investments across the country; there are political reasons to spread the resources.

The federal government needs to deliver the right level of ambition and investment. There is a need for a whole-of-government approach to provide a decarbonization RD&D vision, which may involve re-directing resources, blending the mandates of different DOE offices, increasing flexibility, and rethinking some legacy structures that separate basic and applied research. The federal government has to be willing to take more risk, understanding that some failure is acceptable. A whole-of-government approach is hard, however. On nuclear, for instance, the Department of Defense has seemed more like a customer to the national labs than a partner, and there can be disconnects even between different parts of DOE.

Private capital is investing in innovation as well, with more and more private-sector actors investing in RD&D across power, agriculture, transportation, manufacturing, buildings, and other sectors. Some later-stage funds are showing increasing willingness to write small checks early, while some funds that have focused on the early stages are exploring the addition of funding for later-stage commercialization efforts.   There are also nascent efforts to bring philanthropic support to emerging clean energy innovators working on technologies for hard-to-decarbonize sectors to help them move to commercialization, whether through startups, joint ventures, acquisition by incumbents, or other means.

The dollars required to get technologies past the deployment valley of death, however, are substantial, and very few entities are willing to put in the money to de-risk technologies at that stage and at that scale. There have been some conversations about pooled resources and other types of blended finance to de-risk the first products and markets – to infuse money from multiple sources to buy down the "green premium" of cleaner technologies and allow some of the first markets to gather steam so other more risk-averse investors can crowd in afterward. Not enough people are tackling the commercialization gap, though, and there may be a role for government capital there. For instance, in the electricity space, there is no reason that geographically convenient ratepayers must pay for deployment of new technologies; if there are systemic or societal benefits from bringing the technologies online, then all could pay, which means a larger role for the government to play in commercializing technologies.

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The commercialization valley of death is not just about the flow of money. Most consumers of technologies do not want to take technologies that have just been lab-proven and put them into their facilities. There is an important role for big private companies to take nearly commercialized technologies and prove them in their facilities – to overcome others' resistance to being first.

First movers, such as for advanced nuclear reactors, will still need a lot of help from the government. Private capital rarely operates alone. Many privately funded RD&D efforts have benefited from early public money and Department of Energy support. DOE grants and other forms of support, for instance, increase the number of patents in clean energy development, help companies past the valley of death with higher revenues, and can help clean tech companies succeed. There are linkages between DOE, labs, universities, and private capital. Governments will have to provide billions of dollars to get technologies commercialized.   Like big private companies, governments will also have to be customers, proving the efficacy of the technologies and helping to bring them down the cost curve.

To improve the clean energy RD&D ecosystem, there may be models to learn from, if imperfect ones, outside the energy space. The National Institutes of Health, for example, has some enviable attributes that DOE does not, including a clear mission that politicians and the public can connect to, a system that private industry understands how to enter, a culture of civil service science, and lots of flexibility in resources. Another example may be Sematech, a non-profit consortium to advance American semiconductors that had a clearly defined roadmap to make U.S. semiconductors more advanced and competitive again; with government and private collaboration, it was pretty successful. Sematech highlighted the importance of technical standards collaboration. Technical standards for the electricity system, for instance, are often not free and are not robustly developed in many areas; that could be a fertile area for productive, pre-competitive collaboration.

Europe does a better job than the United States on cross-sector collaboration on innovation. One key difference is that Europe has an open industrial policy discussion, which is weaved into economic and energy policy. There are political leaders, centers of policy leadership, and funding flows allocated to that. That does not exist in the United States; there is no one in the U.S. government tasked with driving industrial policy and related RD&D. It is not just a question of money; the lack of mechanisms to channel it is a big hurdle.

RESILIENCE

The resilience of a community or energy infrastructure, including against the impacts of climate change, generally means the same thing as the resilience of a person – the ability to carry on, persist, and recover when bad things happen. The concept can be defined simply, but what goes into achieving it can be very complicated, implicating how systems are designed, constructed, maintained, and operated. As floods, sea level rise, wildfires, temperature changes, and other impacts of climate change increase, resilience becomes of ever greater importance, particularly in vulnerable regions and communities.

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VULNERABLE COMMUNITIES & INFRASTRUCTURE

A distinguishing feature of resilience is that it is defined by the weakest links in the chain. It takes just one jurisdiction where critical infrastructure fails for an event to have a devastating toll, which means efforts are needed in every community. Individual cities or communities being ahead on resilience only helps people who live in those places. Indeed, depending on the resilience approaches pursued, individual efforts can actually cause harm to neighbors; for instance, one spot building a seawall can push water into neighboring places and make impacts worse.

Resilience has to be part of the context of planning the transformation of energy systems to support a net-zero economy. The resilience of U.S. energy infrastructure is moderate at best, when measured on aspects such as governance, collaboration, asset condition, technologies used, operations, and financial considerations. This is evident amid the onslaught of storms, fires, and other climate impacts. As summers become hotter, droughts become longer, wildfires become more destructive, storms become stronger, and floods become more frequent, pressure is mounting on the electricity system, which is the backbone of the economy and quality of life.

Utilities are therefore investing in resilience. Many utilities have run exercises and scenarios for years as a critical part of assessing vulnerability, improving coordination, and being prepared for emergencies. The national labs can partner with utilities to provide some of the deep analytics and modeling needed to support robust planning for decarbonization, resilience, and equity, including tools and models that jurisdictions around the country can use for realistic scenario planning or gaming.

Utilities in wildfire regions have also invested billions in mitigation, detection, and forecasting capabilities, as well as in emergency preparedness and response. Wireless and broadband technologies can aid in these efforts, allowing near instantaneous communications capabilities even in a far-flung network. For example, by using sensors connected through broadband technologies, an active electricity line that is blown down in an area of dry tinder could be deactivated by network control devices before it hits the ground, avoiding sparking a wildfire. Sensors, data, and digitization can provide situational awareness across vast areas cheaply and reliably.

Resilience is somewhat about system hardening of transmission and distribution systems, but it can also be about distributed resources on either the utility or customer side of the meter. Efforts to improve grid resilience should include localized and decentralized energy options, with incentives targeted for the most vulnerable communities. This can involve microgrids at critical community locations (e.g., to serve as disaster response or cooling centers), energy efficiency to reduce demand, and energy storage of all types and durations to help individual buildings and the overall grid. While distributed energy systems and networks can enhance resilience, they can also make it in some ways more challenging, as the overall system becomes more complex.

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There are political decisions to be made about who bears the costs of enhancing resilience. The resilience of the electricity system, for instance, provides value for society as a whole, not just for utilities and their ratepayers.

In addition, while the costs of resilience investments are high, the costs of failing to make those investments are far higher. It is important to quantify all such costs, as there are clearly public burdens not being factored into costs now. For instance, a single hurricane in one location tripled the youth homeless population there – which is an impact with significant short- and long-term costs that are often left out of analyses. Resilience thus should be thought about in broad terms, beyond just climate. Households and communities are dealing with a series of system shocks, with layered impacts. Solutions should therefore aim to create multiple benefits, factoring in issues as diverse as housing, social cohesion, and healthcare access. Solutions can also create employment gains; there is often talk about investing in clean energy jobs, but there should also be talk about investing in resilience jobs in construction, retail, and more.

Where resilience fails or is too challenging, questions inevitably arise about managed retreat – questions heightened as insurance companies begin to refuse to offer certain types of coverage in high-risk locations. It may be better to work with communities in high-risk areas ahead of time to plan out what the communities want to do if they get hit with events of a certain magnitude, such as dropping premiums to very low levels but relocating if the event happens. This could be fairer than asking communities about relocation after they are reeling from a hard hit, which can lead to disadvantaged communities getting taken advantage of.

NEED FOR FEDERAL LEADERSHIP

The federal government needs to start paying more attention to climate resilience. The federal government is not fulfilling a number of its duties regarding climate-related hazards, which can make it impossible for most local governments to be effective. For example, the data in flood maps is frequently just wrong. Local governments base zoning and other measures on those maps, which makes it hard for most local governments to prepare appropriately.

Few local governments are in a position to make substantial investments in resilience, especially after the hit their budgets have taken from COVID. While more funding is certainly needed, existing sources of funding and authority also need to work together better. Currently, resilience is spread across more than a dozen federal agencies and hundreds of programs. The system is so complex that communities need to hire outside consultants to navigate it, which leaves communities behind that cannot afford that. Similarly, competitive grant programs exist for resilience, but there is a need to close the pre-development gaps that prevent some communities from even applying. Resilience systems need to be redesigned around the most vulnerable communities that are least able to afford to adapt; resources should be explicitly targeted for frontline communities.

The current federal system related to resilience is badly broken and requires systemic change. The government needs to center the issue of resilience and improve federal coordination. Whether through an executive order or otherwise, there is a need for a cross-agency initiative that creates a process for people to regularly come and sit at the same table (or a virtual table) to talk and help each other understand. The initiative will have to have local input and control and support local resilience planning. A focus on participatory planning and policymaking strategies is important, and robust needs and strengths assessments that center community voices should be conducted. The federal strategy also needs to encourage and support collaboration among jurisdictions, across levels of government, and across sectors, including encouraging local communities to partner with the private sector, industry, utilities, nonprofits, and others to increase effectiveness in advancing decarbonization and resilience efforts. There is a need for advanced policy thinking and funding, cross-sector governance and collaboration, and increased use of public-private partnerships.

EQUITY

A big development over the past few years has been the increased acknowledgment of current inequities – underscored by racial justice protests and the COVID pandemic – and direct questions about how to make the zero-carbon transition work for everyone. The transition has to be not only rapid, but also equitable and just.

PROMOTING EQUITABLE SOLUTIONS

The current economic paradigm and energy system do not work for, and have negative impacts on, many communities, particularly communities of color, low-income communities, and frontline communities. These communities were sold dirty plants tied to fossil fuels because they needed jobs, but there are many communities in the United States that still breathe unhealthy air. These are the same communities often suffering the highest COVID infection and death rates, asthma rates, and respiratory illness rates. Black Americans are exposed to far more pollution than white Americans are. The richest 1% in the world produce more than double the emissions of the poorest 50%, who are the ones who will be disproportionately affected by climate impacts. People are dying for an economy that does not benefit them.

Decisions made over the next decade will be crucial to protecting health and a livable climate around the world. The responses to the climate challenge could either widen or narrow existing equity gaps, with profound effects on health and well-being. Solutions built on top of systemic racism make the situation worse; failure to address the inequalities will lead to further social instability, which will undermine economic development. This is a moment in time where there may be opportunities to confront and deal with the structures that have created these inequities, including the justice and health consequences of dirty plants and dirty types of energy being located in communities of color, frontline communities, poor communities, and rural communities. When decisions are studied and made about what industries and facilities are located in frontline communities, it is vital that the people in these communities are sitting at the table. There is a need to be as attentive to policies that address equity concerns, bring people in, and build the coalition needed to perpetuate the clean energy transition as to policies directly focused on decarbonization.

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It is important not to assume that the clean energy transition is inherently good for all populations. (That said, it would be terrible from a justice and equity perspective to not transition quickly, given the impacts both of climate change and air pollution.) If advocates focus solely on reaching climate goals at least cost, they miss opportunities to make the transformation faster and more durable. For instance, even if one thinks distributed renewables are not a big part of the math to achieve emission reductions, investing in them, especially in disadvantaged communities, has a lot of upsides in terms of political economy. Likewise, policies to prioritize EV charger investments in low-income communities or to put more public money into public transit electrification may not have the biggest emission reduction impacts but will be important to expand access and opportunity. Policies to expand broadband access, while not specifically climate-related, could enable more low-income or other customers to take advantage of demand response opportunities. Costs may be slightly higher if high labor standards are hardwired into the transition, and insisting on mitigation for farmers or robust community benefit agreements might add costs for developers, but failing to do those sorts of things invites headwinds to the transition that could put climate goals out of reach. In addition, in the move to a green economy, the focus needs to not only be about creating jobs – with someone else owning the business – but also about creating opportunities for ownership for people who live in these communities.

There have been efforts to advance equity in climate solutions. For example, with opportunity zones, there may be opportunities to direct tax equity into clean energy initiatives in disadvantaged and pollution-burdened communities. Indeed, there are many programs – from utilities, housing agencies, and others – to implement clean energy projects in disadvantaged communities, seeking to make sure everyone is benefitting from the transition, has access to clean technologies, and has efficient housing stock. Since much of the pollution that communities are exposed to comes from vehicles, moving quickly to electrify the transportation ecosystem can also lead to significant health gains, and some utilities and municipalities have put a focus on electrifying transit buses in addition to personal vehicles in part due to the clear equity benefits. It will be important to make the transition one that closes as opposed to exacerbates equity gaps.

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In addition, communities reliant on emitting fuels and industries that will experience negative economic impacts from the transition will also need support. Climate solutions have to include opportunities for their long-term success, including job training and economic development – so these communities have hope and something to gain from the transition. There may be a need for economic incentives for new industries to move into these areas and utilize existing worker skillsets. These communities, though, hear promises of a "just transition" and now dismiss them. Politicians on both sides of the aisle have failed for years to make good on those promises, and there is not an impressive track record of successfully achieving such transitions.

EQUITY & CARBON PRICING

Governments should adopt policies to promote achievement of emission reductions at the lowest possible cost, but there is also starting to be more recognition that carbon pricing by itself may not achieve goals related to equity, environmental justice, labor, and other areas. There is at least a 20-year history of the environmental justice community distrusting market-based approaches to addressing climate change. This has been most evident in California. California, in implementing climate action programs, included environmental equity from the beginning as a foundational goal, with an environmental justice advisory committee and health-based air quality standards. The state's cap-and-trade program has also raised billions of dollars that have been targeted to the most disadvantaged communities in the state, creating some well-received programs and promoting better land use and transit alternatives. Nevertheless, there are still fundamental disagreements in the state about how to approach the nexus of equity and energy policy. Environmental justice groups have been adamantly opposed to any form of cap-and-trade program from the beginning, preferring mandates to reduce emissions from problematic sources.

From the perspective of the environmental justice community, carbon prices kick offline the least efficient fossil generators – the most expensive or dirtiest ones that are least able to internalize the price and stay viable. Those plants, though, are not necessarily the ones having the biggest air pollution health impacts in communities. Advocates would prefer more command-and-control methods to get those plants offline. It is not so much that environmental justice advocates oppose carbon pricing per se as that they support more government intervention in what comes on and off line, where, and how fast. While quantified analyses of cap-and-trade have shown it does not lead to the negative distributive impacts that some have feared, market-based policies need to be coupled with other state policies that incorporate more of an equity lens.

EQUITY & POWER MARKETS

It may not be possible to engineer a wholesale market structure that adequately addresses environmental justice concerns, and regulators in other areas have more expertise than FERC and state utility commissions in issues tied to pollution, environmental justice, economic development, and community revitalization. Surveys of utility customers also show that affordability and reliability are their focuses, and social justice, environmental justice, and environmental responsibility in the electricity space have to be pursued with that in mind. That does not mean, though, that environmental justice can be disregarded by those involved in power markets. It is hard to argue that markets and rates are just and reasonable if they perpetuate the inequities in the current electricity system.

Equity and justice issues have to be brought into thinking around power market design. Markets are generally designed to clear according to price. Affordability is key, but environmental, economic, equity, and public health considerations should also come into play, and those issues have costs too. Whether rates are just and nondiscriminatory depends on how one defines the universe of factors to consider, and benefit-cost analysis could be a useful tool to define which benefits and costs are considered and how they are weighted. Some externalities can be priced, through metrics such as the social cost of carbon. Many other issues of concern regarding the distributional impacts of policy and markets may not be amenable to a price, but they may still be amenable to detailed quantified analyses that can lead to better informed decisions.

Environmental justice concerns can also be addressed in power market governance structures, such as through enhanced transparency of information and greater efforts to make sure people who are less advantaged get represented better. For example, consumer advocates could be strengthened and given new responsibilities to bring additional information and voices to the table.

CORPORATE ACTION

The urgency of the climate challenge is leading to a wave of new and increased corporate targets, goals, and actions.

TARGETS & GOALS

2020 has seen a wave of major announcements of jurisdictions (national and subnational) and companies making commitments to zero-carbon and other clean energy goals. Over the last decade, end users, especially corporate ones, have been huge drivers of the transition to clean energy, with growing adoption of 100% zero-emission energy targets. The trend started with the high-tech sector but quickly expanded across retail, industrials, and others, spurred by demands from customers and shareholders. In 2020, the trend included both buyers and producers of energy, including U.S. utilities and global oil and gas companies. Most major utilities in the United States have now made such commitments.

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These corporate goals are getting more ambitious, and not only in terms of the numerical targets and achievement dates. For instance, commitments by major multinationals often include their supply chains, and sometimes their customers' use of products. A different manifestation of heightened ambition can be seen in corporate goals not just to match annual energy consumption with renewable energy purchases but to achieve more granular, 24/7 carbon-free energy. A focus on annual volumes masks the need to figure out how to integrate more zero-carbon resources into the grids where corporate facilities are actually located, in order to provide clean energy on an hourly basis and manage seasonal variations. This means going beyond just wind and solar to find other resources – currently more expensive ones – that can complement variable renewable generation. Those pioneering the 24/7 approach are developing methodologies that followers can later use, such as attributing value to projects based on location and time of production in the context of the existing grid mix, as well as focusing on grids and hours where carbon emission reductions are most needed (i.e., where the most emitting resources can be displaced). Those lenses lead to a different geographic distribution of clean energy projects and a different technology portfolio than would otherwise be the case.

Setting targets is the easy part; achieving them is hard. These advanced ambitions include, explicitly or implicitly, calls for assistance. It is not clear today how these goals will be achieved, and the companies need technologies, infrastructure, policies, financing, and advanced analytics to create implementable blueprints to get there. Data is essential, so corporates can know what their energy consumption is from a carbon and fuel mix perspective. All customers need tools and visualizations to help them understand what they can do and what the challenges are for decarbonizing the grid. For big customers, energy usage and fuel mixes could look markedly different from facility to facility.

Smaller companies that lack the resources of the big tech companies should focus on the one or two things they really want to set targets for and then go after them. Easy starting places would be things like energy efficiency and renewables, where the technologies exist today and the path forward has been well established by others. Incremental progress goals are also important; they set companies on the path and give them the internal skillsets that enable them to then set and achieve more ambitious goals. There are growing numbers of platforms and associations that can help smaller consumers start on their journeys and learn from others' experiences.

IMPACTS OF CORPORATE ACTION

When corporate leaders put these sorts of targets and initiatives out in the public sphere, they can spur discussions, help others look at and adopt similar goals, and create momentum and demand in the market for new solutions. By being transparent about their methodologies and pushing for improved data access so users (including smaller ones) can better understand the electricity they are consuming, corporate leaders can pave the way for others to follow.

Corporations can use their buying and advocacy power to push forward the energy future. Utility leaders are aware of what major corporate energy users, particularly the big tech companies, are seeking in terms of zero-carbon energy, and that demand has been a wake-up call for utilities to think about how to market themselves. Big energy purchasers can have bilateral negotiations with utilities to create bespoke tariffs, but those take years of effort; they prefer to have flexible organized markets they can just plug into.

Large companies have been bringing significant amounts of renewables to market for years, but they are going beyond that as well. In addition to investing in on-site and off-site renewable energy projects, they are deploying electric vehicles in large numbers, advancing energy efficiency, and, in a few cases, announcing funds to invest in novel climate solutions. Corporates are also partnering with utilities on resources that both serve corporate needs and add value to what is already on the grid. For instance, using energy storage just for corporate needs might lead that resource to be underutilized, but partnering with utilities to share the storage assets could maximize the value of those assets and improve the economics. Companies making big purchases of clean energy, electric vehicles, storage, and other aspects of the climate solution set can help create market forces to spur more supply at more affordable prices.

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This corporate power is not limited to domestic markets. U.S.-based multinationals can play a role in helping to advance the export and utilization of American-made clean energy technologies globally, through their operations and supply chains. U.S. multinationals can also be the bankable anchor customers for new U.S. investments in international clean energy projects; it is hard to get financing for a large-scale energy infrastructure project without a long-term off-taker agreement in place.

Climate change is a systemic problem, though, and there are limits to what even the largest individual companies can do. There needs to be a shift so that corporate responsibility and leadership mean a greater focus on policy advocacy. Most companies, while purchasing clean energy or taking other steps to reduce emissions, could be doing more to advocate for a broader policy set, including talking to congressional staff and putting money behind advocacy. Engagement in the policy landscape is what changes things systemically.

U.S. POLICY & POLITICS

There is huge uncertainty around the policies the United States may utilize to address climate change moving forward, hinging in no small part on the outcomes of the November 2020 presidential and congressional elections.

PARTISAN APPROACHES & POTENTIAL FOR BIPARTISANSHIP

While the presidential election is clearly enormously consequential for climate and energy issues (and many other issues), the prospects for climate policy action also depend heavily on which party controls the Senate. Assuming the House remains under Democratic control, it will continue putting climate action into every appropriate legislative vehicle, including on appropriations, defense, and infrastructure. There are numerous ways Democrats will be looking to address the climate crisis that do not look like typical climate policy. The key question is whether the House will have partners in the White House and the Senate for bold action. It is always important to remember, though, that the parties are not homogenous, and there is a range of views on climate and energy issues within each.

If Republicans maintain control of the White House and/or the Senate, then the prospects for climate-related legislation are very similar to where they are today. The climate rhetoric out of the White House (and conservative media outlets) appears to be an anchor on what the Republican Party can do on climate at the national level, but while there are still some Republicans in Congress who espouse climate denial or agnosticism, there are many fewer than in the past, and their role in the Republican conference in Congress is much less than it used to be. The rhetoric of "denialism" is being overused. There now seems to be an ever-sliding scale, where failure to support any given policy or approach is deemed denialism, but that kind of rhetoric keeps the parties ever further apart and in their corners. Republicans in Congress seem to be focusing on innovation and on finding climate solutions that are affordable from a global perspective. Republicans have historically not been supportive of a clean energy mandate or a carbon price, though there are some members looking at each.

If the Democrats take control of the White House and the Senate and the filibuster remains in place, the prospects for legislative climate action are, again, very similar to where they are today – though the regulatory agenda would clearly be different. A fair amount could also be accomplished through the budget reconciliation process. Both parties have used reconciliation in the past to advance priorities. Reconciliation could be used to boost funding for existing programs in agencies and state energy offices, to adjust the tax code to spur greater clean energy deployment, and potentially to implement a carbon tax. Reconciliation takes some of the precision out of the suite of actions, though, as it is harder to do new programs and complementary policies like in a legislative, negotiated package.

If the Democrats take control of the White House and the Senate and do away with the filibuster, the potential for legislative climate action is much greater and quite different. The role of carbon pricing as part of that action, though, is unclear. Views on carbon pricing have changed a fair amount for Democrats since the Waxman-Markey bill in 2009. That was a cap-and-trade system, which can be complicated to establish, and it is not clear how anything like one would move in the current U.S. political environment. (Unlike what happened in California, Congress would not delegate creation of a cap-and-trade program to an expert agency.) There is still some support for a carbon tax, but a carbon tax has the most impact in the power sector, which is the sector that has already taken a fair amount of action to reduce emissions and where dispatch is already increasingly favoring zero-carbon sources. (The electric power sector will not get to

Paris goals absent policy, though; there have been reductions in emissions, and there will be more, but reductions will flatten out if the technology of choice for most hours of the year is uncontrolled natural gas.) A carbon price could be a component of a suite of policies, potentially as a backstop and a source of additional funding for needed investments, but it no longer seems to be central to policy discussions. Instead, people have been focusing more on how to move particular sectors and on other ways of driving clean energy investment. The need for climate action has also grown more urgent since Waxman-Markey a decade ago, so it is unlikely that there would be enough Democratic votes for a goal that is not stronger than that bill's goal of an 80% reduction by 2050.

There may be more room for bipartisanship, including on issues of resilience, agriculture, and innovation – where the parties are not that far apart, though there are still differences regarding the scale and type of action to take.

There has been some budding bipartisanship around the acknowledgment of climate change as an issue to grapple with. There may be more room for bipartisanship, including on issues of resilience, agriculture, and innovation – where the parties are not that far apart, though there are still differences regarding the scale and type of action to take. If the Democrats retain control of the House and take control of the Senate, it will be interesting to see if climate action is focused in one or two big packages that include policies that will clearly divide the parties (e.g., a clean energy standard to achieve 100% zero-carbon power by 2035) or in lots of smaller bills that might have a greater chance for bipartisanship.

If there is to be a bipartisan deal on emissions, it will have to be a tech-inclusive one. Tech-specific options, such as renewables tax credits, may be important in the short term to spur deployment, but any and all solutions and tools should be on the table in a tech-agnostic decarbonization pathway. Some states have already pioneered such policies. New York, for instance, has tech-agnostic commitments about achieving carbon-free electricity, specific targets for technologies such as offshore wind, energy storage, and solar, and a Clean Energy Standard that gives the state leverage to procure clean energy while lifting up labor standards and environmental justice goals.

THINKING GLOBALLY

Climate policy discussions in the United States and Europe tend to be dominated by domestic considerations and approaches. While it is very important for the United States and Europe to reduce their greenhouse gas emissions, the vast majority of emissions are going to be coming from emerging economies, driven by higher incomes, population growth, and urbanization. Just the *growth* in emissions in developing Asian countries will exceed by 2050 the total U.S. emissions today. Many millions of people continue to lack reliable access to electricity in India alone. China has brought dozens of gigawatts of new coal online in 2020 and is financing and constructing dozens more around the world. Within the next decade or two, the majority of Africans will be living in cities, which means big growth in energy demand. If U.S. policy focuses investments on technologies that are more expensive, it could cause less investment in innovations in decarbonization technologies that would be more affordable and exportable globally. There is no excuse for U.S. inaction, but this is a global challenge. The United States has to focus on both reducing its own emissions and affecting the development trajectory of the rest of the world; actions taken domestically should have an eye on exporting technologies and financing projects abroad that support U.S. manufactured goods and U.S. jobs.

The United States, however, is far behind global competitors in taking advantage of the opportunities in the energy growth markets. China, in particular, is a dominant actor on the global energy stage. Through its Belt and Road Initiative, China is building infrastructure that emerging economies in Africa and elsewhere desperately need. The United States has no choice but to work or partner with China, but that is difficult since China is also a geopolitical foe and a competitor that does not play by the same rules that others do; the relationship between China and the United States has deteriorated.

Nuclear power is an example of an area in which the United States is falling behind on the global stage. Most future electricity demand will be in countries that are either ready for advanced nuclear plants or are likely to be by the end of this decade. The United States is making advanced nuclear technologies, but Russia is already aggressively marketing its small modular reactors in Africa and elsewhere, as part of an integrated package of financing, construction, and other support. U.S. laws, proliferation controls, and safeguards are so restrictive that the United States is ceding markets and technological leadership to global competitors. Still, there is a lot of interest and opportunity around the world in U.S. nuclear technologies, and the past few years have seen some federal efforts to level the playing field and better compete against other countries not requiring the same nuclear standards. (The World Bank also has a de facto ban on doing anything in nuclear, and many other multilateral development finance institutions borrow the World Bank's policies, so there is a ripple effect across the entire financial architecture meant to support infrastructure in emerging markets.)

While it is very important for the United States and Europe to reduce their greenhouse gas emissions, the vast majority of emissions are going to be coming from emerging economies, driven by higher incomes, population growth, and urbanization.

Given the still-heavy reliance of many parts of the United States and the world on coal and natural gas, CCUS can also be very important, both in terms of protecting jobs, preserving the value of trillions of dollars' worth of existing assets and infrastructure, and paving the way for decarbonization of other industries. Failure to develop exportable CCUS technologies in the United States cedes more control over global energy to countries that will be continuing to exploit their fossil fuel reserves and building fossil fuel infrastructure.

America's ability to compete with countries such as China and Russia in overseas markets has been further hindered by some counterproductive U.S. government actions taken over the past few years. For example, countries that would like to get American technologies are more skeptical of U.S. overtures due to actions such as the U.S. withdrawal from the Paris Agreement. The United States is also far behind in government support for the types of domestic market creation needed to enable exports. It does not have national industrial policy that could focus on making and exporting clean energy, the way China does, and it lacks clear, ambitious targets and goals that could help the United States develop the technologies and services needed both domestically and globally. Rollbacks of fuel economy standards, for example, could hinder U.S. vehicle manufacturers' global market shares as big markets such as Europe and China move toward EVs. U.S. policy should help buttress where American companies would like to go and where global markets are headed so that companies get there ahead of – or at least at the same time as – companies that are getting more support from their governments.

The U.S. government is not well organized to promote U.S. energy technologies in the higher-risk markets where global energy demand is growing, given its fragmented government and private-sector-led business model, but it can do more to get out of its own way and positively support U.S. energy technologies. There is a vital role for public policy tools such as the ones the U.S. development bank (the International Development Finance Corporation) and export credit agency (the U.S. Export-Import Bank) provide to help de-risk investments. The DFC partners with the private sector to finance challenges in the developing world, including energy, often leveraging private investment and mitigating country risk; in 2020, the DFC removed a policy prohibition on nuclear power finance. ExIm complements private-sector lending institutions to finance the foreign purchase of U.S. goods and services, including related to renewable energy, energy efficiency, energy storage, and other areas. ExIm had been shuttered for more than four years, which diminished U.S. leadership on clean energy and yielded more of the global supply chain to China; when Congress reauthorized it in late 2019, it granted ExIm new authority to compete with Chinese financing, including in renewables. Both DFC and ExIm could be powerful global mechanisms for scaling up clean energy.

In general, trade, climate, and clean energy policy need to be joined into a common framework so clean energy development can be promoted domestically in ways that enable global exports. It is important to consider embodied carbon

– the GHGs associated with production of technologies – when thinking about climate, energy, and trade policy. Policies that reward the cleanest producers of any given product will generally help U.S. producers. For instance, Chinese carbon intensity is higher than America's, so there is climate benefit to producing technologies (e.g., solar panels) in the United States versus the cheaper ones in China. Likewise, some argue that support for use of U.S. natural gas around the world advances decarbonization because the competition for that gas comes from Russia, whose production has a higher carbon footprint. Merging trade policy with climate policy in the right way could create potential for some U.S. national consensus, reducing global emissions by bringing manufacturing and production back to the United States.

In general, trade, climate, and clean energy policy need to be joined into a common framework so clean energy development can be promoted domestically in ways that enable global exports.

Some in the United States and Europe have talked about border carbon adjustments to protect domestic industries, account for the carbon embedded in imported products, and incentivize other countries to adopt strong emission reduction programs. Border carbon adjustments are very difficult to do, though, especially in ways that do not harshly impact developing countries; they can be seen as a back-door climate mitigation approach that forces developing countries to do things that they have not agreed to do, thereby abrogating the principle of common but differentiated responsibilities under the Paris Agreement and the UN Framework Convention on Climate Change. Conversations are needed about how to help low- and middle-income countries develop on a cleaner path to participate in global markets.

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APPENDICES: AGENDA

MONDAY, OCTOBER 5

Opening Session

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

NOON – 12:50 PM ET — **MONDAY PLENARY - Opening Remarks & Briefing Room: A New World**

COVID-19 has radically transformed the world economy and with these changes the energy sector faces new challenges and increased uncertainty. How has COVID-19 impacted energy and climate policy in the United States and around the world? What other pivotal variables are in play?

Welcome and Opening Remarks:
Greg Gershuny, The Aspen Institute
Cheryl LaFleur, Columbia University's Center on Global Energy Policy
Rich Powell, ClearPath

Moderator: Rich Powell

Discussants:
Trevor Houser, Rhodium Group
Doug Arent, NREL
Melissa Lott, Columbia University's Center on Global Energy Policy

12:50 – 1:10 PM ET — **Breakout Discussion Session**

1:20 – 2:35 PM ET — **SESSION 1A: Policy for Deploying and Scaling Clean Electricity Technologies**

Newly developed clean energy technologies, from advanced and small modular nuclear reactors to large offshore wind to natural gas with carbon capture, utilization, and storage, offer the potential for new tools to accelerate the decarbonization of the electricity sector. How might we implement policies that further enable deployment of emerging clean electricity technologies at the scale necessary for the challenge at hand?

Moderator: Cheryl LaFleur & Rich Powell

Discussants:
Kristine Svinicki, NRC
Ali Zaidi, NY Department of Energy
Kathryn Arbeit, First Solar

SESSION 1B: Mobility of the Future

Getting from point A to point B is changing. Prior to the COVID-19 pandemic, cleaner and shared transportation options were growing in scale and popularity across the US. What technologies, policies, and infrastructure do we need to enable safe and clean transportation options in this new world?

Moderator: Bryan Hannegan

Discussants:
Robert Grant, Cruise
Sam Arons, Lyft
Beth Osborne, Transportation for America
Dan Sperling, UC Davis

2:45 – 4:00PM ET **SESSION 2A: Resilience & Energy Infrastructure**

Climate change impacts, like extreme weather, sea level rise, and droughts, disproportionately affect vulnerable communities. How can states and local authorities better prepare for and manage these extreme events? How might we strengthen federal adaptation policies to meet communities' needs? How do we improve grid resilience to secure our energy system? How can policy help communities most vulnerable to extreme weather be more resilient?

Moderator: Cheryl LaFleur

Discussants:
Melissa Roberts, American Flood Coalition
Sekita Grant, Climate Justice Advocate
Nancy Sutley, LADWP
Jan Vrins, Guidehouse
Caroline Winn, SDG&E

SESSION 2B: Getting Infrastructure Built: Pathways to Permitting and Building Infrastructure Necessary for Deep Decarbonization

Achieving state clean energy goals by 2050 will require a substantial amount of infrastructure to be permitted and built on an expedited timeline. Scaling infrastructure deployment at the level necessary to achieve these ambitions may require changing policy and permitting requirements. Who are the key players that need to be involved in creating a consensus surrounding regulatory reform? What mechanisms can be used to expedite the permitting and environmental review processes? Do environmental tradeoffs come into play, and if so, how should policymakers balance competing interests?

Moderator: Jim Connaughton

Discussants:
Neil Chatterjee, FERC
Katie McGinty, Johnson Controls
Manisha Patel, WSP
Colette Honorable, Reed Smith, LLP

4:00-4:45 PM ET **Day 1 Co-Chair Wrap Up and Energy Week Virtual Reception**

TUESDAY, OCTOBER 6

1:00 – 2:15 PM ET

SESSION 3A: The Role of Research, Development, & Demonstration

The U.S. Department of Energy national laboratories, as well as private ventures, play critical roles in developing clean energy technologies. Therefore, sufficient funding for research, demonstration, and deployment of technologies is crucial to accelerating the transition of our energy system to achieve emissions reduction goals. How can private and federal funding be directed to catalyze these new technologies?

Moderator: Roger Ballentine

Discussants:
Martha Symko-Davies, NREL
Varun Sivaram, Columbia University's Center on Global Energy Policy
Mark Peters, INL
Michael Boots, Gates Ventures

SESSION 3B: Harnessing the Power of the Market: The Role of the Debt and Equity Capital Markets

The transition of the energy system is already underway and is being financed almost entirely by private capital responding to market and regulatory incentives. What are the best ways to harness this capital to achieve optimal outcomes for all stakeholders? What are the tradeoffs between providing incentives for capital and operating efficiency while also keeping the cost of financing low and still avoiding the moral hazard that accompanies the elimination of investor risk?

Moderator: Jim Murchie

Discussants:
Nate Gabig, KPMG
Nancy Pfund, DBL Partners
Susan Nickey, Hannon Armstrong
Rejji Hayes, CMS Energy

2:25 – 3:40 PM ET

SESSION 4A: Technological Challenges to Scaling Clean Energy

As new clean energy technologies scale up, novel technological and resource challenges may arise. What are the technological challenges we face to deploy clean energy at the scale and speed needed to combat the climate crisis? What are the hurdles to sourcing socially and environmentally responsible building blocks for clean electricity technologies?

Moderator: Rich Powell

Discussants:
Melanie Kenderdine, EFI
Bill Brown, 8 Rivers Capital
Barbara Humpton, Siemens
Annmarie Reynolds, AES

SESSION 4B: The Role of Carbon Dioxide Removal

The removal of carbon dioxide from the atmosphere through both natural solutions as well as direct air capture will play an important role in limiting warming and achieving the "net" in net-zero. What policies are needed to lower costs and deploy carbon removal projects? What role should corporate investment play?

Moderator: Roger Ballentine

Discussants:
Julio Friedmann, Columbia University's Center on Global Energy Policy
Elizabeth Willmott, Microsoft
David Elenowitz, Zero Carbon Partners
Will Gardiner, Drax

3:40 – 3:55 PM ET **WRAP UP**

WEDNESDAY, OCTOBER 7

NOON – 12:30 PM ET **WEDNESDAY PLENARY - Corporations Moving the Dial**

Corporations that are large energy consumers have an unparalleled ability to influence the global climate in general, and the energy system in particular – both positively and negatively. What motivates corporations to make more responsible energy sourcing decisions? What will it take for corporate emissions reduction goals to become reality? What barriers exist (policy, regulatory, procurement, deployment, infrastructure, etc.) that make these goals seem difficult to achieve?

Moderator: Cheryl LaFleur

Discussants:
Jake Oster, Amazon
Maud Texier, Google

12:30 – 12:50 PM ET **Breakout Discussion Session**

1:00 – 2:15 PM ET **SESSION 5A: Designing the Next Generation Wholesale Markets**

The current wholesale energy market structure is inadequate to achieve deep emissions reductions. How might the regulatory regime be modernized to better align with low carbon goals? Is new legislation needed? What incentives and regulatory design revisions could pave the way for a wholesale electricity markets that incentivizes zero emissions?

Moderator: David Hill

Discussants:
Rich Glick, FERC
Janet Gail Besser, SEPA
Kathleen Barrón, Exelon
Brian Janous, Microsoft

SESSION 5B: Carbon Utilization: Beyond Enhanced Oil Recovery and Storage

Carbon Dioxide captured from the atmosphere or from powerplants or other point sources have the potential to be turned into a market commodity. What is the near-term and longer-term usage potential of captured carbon and how could captured carbon be commercialized?

Moderator: Marcius Extavour

Discussants:
Etosha Cave, Opus 12
Jan Mazurek, ClimateWorks Foundation
Michael Webber, ENGIE

2:25 – 3:40 PM ET

SESSION 6A: Building Smarter Cities: Digital, Social, and Physical Infrastructure for a Low Carbon Urban Future

Modernizing cities to better meet societal needs while simultaneously lowering their carbon emissions could improve the quality of life of residents and decrease environmental footprints. But outdated infrastructure, lack of digital and wireless integration, and spatial planning that is not optimized for safe, accessible, and low-carbon lifestyles are factors that make many of our existing urban ecosystems increasingly obsolete. How could COVID-19 spur changes in the role of cities in the United States? How could urban modernization improve energy system resilience? How does land-use and transportation infrastructure need to evolve to meet the changing needs of urban Americans in environmentally conscious ways?

Moderator: Clint Vince

Discussants:
Morgan O'Brien, Anterix
Paula Gold-Williams, CPS Energy
Gil Quiniones, New York Power Authority
Padden Murphy, REEF Technology

SESSION 6B: Decarbonizing the Industrial Sector

Achieving economy-wide deep decarbonization requires significant innovations in heavy industry sectors such as industrial and manufacturing processes like concrete, steel, glass, and petrochemicals. What policy levers and R&D are needed to move toward cleaner industrial processes? What promising technological solutions exist and how might one scale those projects?

Moderator: Kyle Danish

Discussants:
David Sandalow, Columbia University's Center on Global Energy Policy
Rebecca Dell, ClimateWorks Foundation
Shreya Dave, Via Separations
Meredith Annex, BloombergNEF

3:40-3:55 PM ET

WRAP UP

THURSDAY, OCTOBER 8

NOON – 12:30 PM ET **THURSDAY PLENARY – Making the Clean Energy Transition Work for Everyone: Equity and Justice in the Transition**

Low-income communities, and predominantly Black, Indigenous, and communities of color are disproportionately impacted by the detrimental effects of climate change. These communities have historically struggled from severe environmental harms which are now being exacerbated by extreme weather and pollution. Likewise, some on the forefront of the energy transition are also grappling with financial and emotional turbulence as their longtime careers are eliminated, such as workers in coal mines or at retiring power plants. How can accountability be maintained when considering climate justice? What solutions exist for those who fear they will be left behind as our energy system continues its transition? What is the role of corporations and industry leaders in bridging these gaps?

Moderator: Jason Bordoff

Discussants:
Mary Nichols, California Air Resources Board
Lisa Barton, AEP
Catherine Flowers, Center for Rural Enterprise and Environmental Justice

12:30 – 12:50 PM ET **Breakout Discussion Session**

1:00 – 2:15 PM ET **SESSION 7A: Exporting US Technology: How to Build U.S.-Developed Clean Energy Technology Around the World**

Over the past few congresses, we have seen unprecedented support for clean energy innovation. As these new technologies become ripe for broad deployment, many questions remain surrounding the transfer of American clean energy technologies abroad. What does the global market for clean energy technologies look like? What role can various energy technologies play in international development? What competition do we face from China and Russia? And finally, what needs to be done to best position government agencies and their various tools to overcome the hurdles presented in these questions?

Moderator: Rich Powell

Discussants:
Todd Moss, Energy for Growth Hub
Amy Jaffe, Tufts University Fletcher School
Kimberly Reed, U.S. Export Import Bank
Dave Banks, House Select Committee on the Climate Crisis

SESSION 7B: Heavy Duty Transportation: Marine Shipping, Aviation, and Trucking

Transporting goods, especially long-haul shipments via planes, ships, and trucks, remains an integral component of the global economy. Without the ability to electrify all heavy-duty transportation, what low carbon fuels have commercialization and deployment potential? What is the role of hydrogen and biogas in aviation and shipping? What "out of the box" alternatives may transform the future of distributing goods?

Moderator: Antoine Halff

Discussants:
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Thomas Healy, Hyliion
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2:15 – 2:30 PM ET **CLOSING REMARKS**

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