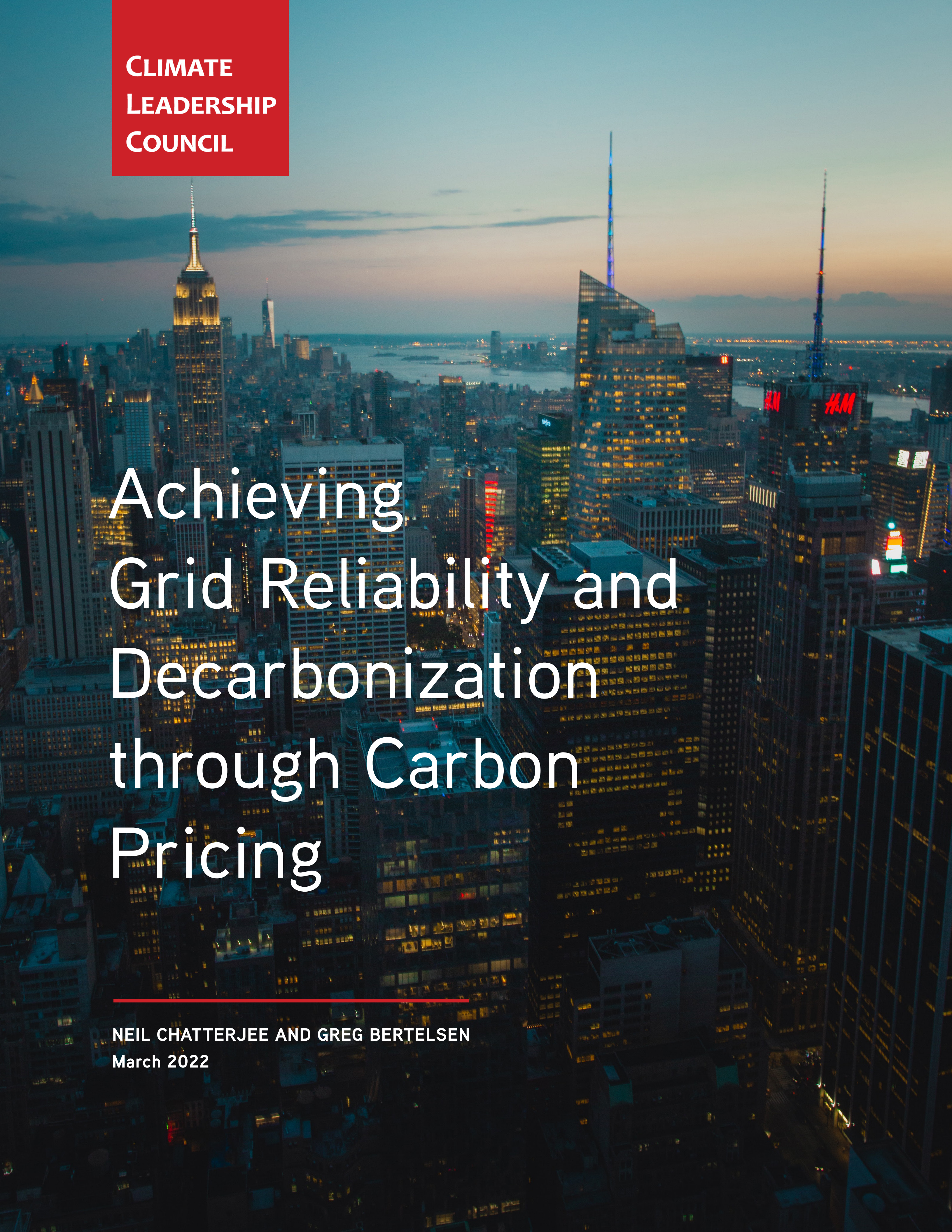

Climate Leadership Council

Achieving Grid Reliability and Decarbonization through Carbon Pricing

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EXECUTIVE SUMMARY

Extreme weather events are increasing in frequency and duration, placing unprecedented strains on the U.S. electric power grid. When the grid fails, the human and economic toll can be staggering, amplifying the already-catastrophic costs associated with climate change. At the same time, extreme weather events have heightened the urgency to rapidly decarbonize the U.S. and global economy—including the power sector—to address climate risks.

The hard truth is that rapid decarbonization poses a challenge to grid reliability. The entity charged with safeguarding grid reliability in North America, the North American Electric Reliability Corporation (NERC), reports that managing the pace of change in the power sector, as we move away from traditional to zero-carbon variable energy resources, is the greatest reliability challenge we face today.[1]

And even as extreme weather and decarbonization put the grid to the test, we are moving toward *an even more grid-dependent future*. To meet decarbonization goals, many experts agree that we must electrify much of the transportation, building, and industrial sectors. By some accounts, electrification will triple our nation's dependence on the grid. This adds pressure on federal leaders to promote policies that support reliable, clean electricity at low cost.

As we face these converging challenges, we need to be clear-eyed. Despite rapid innovations in the power sector, we have not yet reached the point where we can move to a 100% carbon-free power sector—at least not *today*. Large-scale infrastructure investment and technology advancements in the areas of long-duration storage, next-generation nuclear, hydrogen, advanced grid-management tools, and carbon capture, among many others, will be required to support the carbon-free grid of the future. In the near- and medium-term, we will continue to rely on some traditional generation resources, including nuclear and natural-gas power plants, to support grid reliability while we integrate increasing levels of zero-carbon resources.

We also have a finite amount of taxpayer and investment dollars to usher in the grid of the future—and consumers' tolerance for surging utility bills has a limit. As electrification puts upward pressure on electricity demand and American families and businesses rely on electricity to meet more of their energy needs, we need to transform the grid while protecting consumers from unpredictable or unsustainably high electricity prices.

In this moment, policymakers face a pivotal question:

How can we best support rapid decarbonization… while maintaining the reliability of our power grid… and accomplish these twin goals at least cost to the American people?

Fortunately, there is a clear answer: Federal legislation to implement an economy-wide carbon price.

Grid reliability is the ability of grid operators to meet electricity demand today and in the future.

Consensus is growing that economy-wide carbon pricing is the most effective (and cost-effective) pathway toward deep decarbonization.

There are three primary policy pathways to tackling carbon emissions: regulations, subsidies, and carbon pricing. A gradually rising carbon price will unleash market forces to drive consumers and businesses across all sectors of the economy to increase energy efficiency, substitute higher emitting activities with lower emitting activities, and pursue innovation and investment in a carbon-free future. Every dollar contributes to emissions reductions, and dollars can also be returned to American taxpayers and families through carbon dividends.[2] By contrast, regulations and subsidies can sometimes take the form of inflexible, costly programs that reward specified policy outcomes (e.g., deployment of targeted technologies) without regard to other important considerations such as whether they support grid reliability, whether they are cost efficient, and whether there is a correlation between dollars spent and emissions reduced.

Economy-wide carbon pricing stands apart because it is naturally aligned with grid reliability.

Grid reliability is, in its simplest form, the ability of grid operators to meet electricity demand today and in the future. With a predictable price on carbon emissions, the resources that will enter or remain in the market over the long-term—and that will be dispatched by grid operators in the near-term, moment-to-moment—will be the resources that can meet electricity demand where and when it arises in the manner that has the lowest costs, including carbon costs. More simply: carbon pricing inherently supports grid reliability at least cost while we decarbonize.

Other regulation- or subsidy-based policy tools may lack the key features of carbon pricing that place it in alignment with efficiently supporting grid reliability.

Here’s Why:

- **Carbon pricing values all emissions reductions.** Carbon pricing flexibly values all emissions reductions, including emissions savings that result from optimizing existing zero- and low-carbon resources; incremental emissions improvements, such as those associated with fuel switching or improved thermal efficiency; and energy efficiency and demand response measures. Policies that fail to recognize the full suite of emissions reductions that can be unlocked *today* leave them on the table, along with reliability-enhancing attributes and possible cost savings.

- **Carbon pricing is technology- and location-neutral.** Because carbon pricing does not pick which zero- and low-carbon options contribute to the resource mix, or choose where new generation is located, it efficiently moves the power sector toward the right set of resources to deliver emissions reductions and ensure sufficient energy supply and operating reliability to meet customer demand, all at least cost. Policies that favor certain energy resources over others or require new resources to be sited in certain locations can drive investments in a manner that may be out-of-sync with reducing emissions efficiently while supporting grid reliability.

- **Carbon pricing sends price signals that work together to drive emissions reductions and support reliability.** Carbon pricing sends a price signal to reduce emissions; it is also added to the existing price signal to serve energy demand where and when it is needed (or, where possible, to reduce demand). These clear economic signals seamlessly work together to drive decarbonization while supporting reliability.

- **Carbon pricing supports long-term infrastructure investments, innovation, and market reforms**. Infrastructure investments and innovation are critical to decarbonization. Carbon pricing sends a steady, predictable economic signal. This provides investors, grid operators, and power system planners with better data to forecast supply and demand trends and accommodate emerging and new technologies with a variety of attributes to build out the grid of the future. Predictable price signals also support organized market reforms, which may be required to efficiently value reliability attributes as our resource mix evolves. A patchwork of other, constantly evolving policies lacks the long-term clarity and stability required to support durable investments, innovation, and market structures.

- **Carbon pricing is economy wide.** Reliability experts are clear: squeezing carbon entirely out of the power sector is a long-term goal; it will take innovation and investment in the years ahead. Because economy-wide carbon pricing spurs emissions reductions across all sectors and fosters innovation, it allows the U.S. to decarbonize its entire economy rapidly while creating headroom for the power sector to decarbonize in a manner that supports reliability.

In this paper, we first highlight three converging forces that create urgency for policymakers to coalesce around a federal decarbonization policy that promotes grid reliability at least cost.

Next, we unpack the basics of grid reliability and how these three converging forces create new reliability pressures.

Finally, we walk through why carbon pricing is the optimal policy tool to achieve the twin objectives of promoting reliability at least cost and pursuing economy-wide decarbonization.

Three Forces Converge:

EXTREME WEATHER, THE EVOLVING RESOURCE MIX, AND ELECTRIFICATION

In the United States and around the globe, there is urgency to reduce carbon emissions. However, there must also be urgency and focus on supporting grid reliability at least cost as we rapidly decarbonize. We highlight three forces that are converging to create this urgency.

Three Challenges to Grid Reliability

01 Extreme weather that is pushing the grid to the brink at staggering costs;

02 The rapid changes already occurring as competitive forces and government policies drive to a new resource mix;

03 The accelerating push toward electrification, which will increase electricity demand while also amplifying the importance of grid reliability.

Extreme Weather

The U.S. electricity grid is increasingly battered by extreme weather events. In 2021 alone, the U.S. experienced 20 weather-related events that caused an estimated $145 billion in damage. In the last five years, the cumulative financial toll of extreme weather events has reached nearly $750 billion.[3]

This coast-to-coast trend cannot be ignored:

In February 2021, a cold weather event pummeled Texas and the South-Central U.S., plunging more than 4.5 million Texas residents into the dark and taking at least 210 lives.[4] Texas suffered estimated financial losses ranging from $80 to $130 billion.[5]

Later in 2021, record-breaking heat waves in the Pacific Northwest blacked out thousands of customers,[6] becoming the most deadly weather event in Washington state's history.[7]

Extreme heat in California in August 2020 spurred rotating blackouts.[8] Wildfires fueled by heat and drought also have ravaged California's infrastructure, prompting utility Pacific Gas & Electric to announce in summer 2021 that it would underground approximately 10,000 miles of power lines at an expected cost of $15-30 billion.[9]

The East Coast also is vulnerable, as became clear during the polar vortex of 2014.[10] New England's grid operator calls energy adequacy the most critical risk facing the region, warning that extreme weather events exacerbate the system's vulnerabilities.[11] NERC leadership identified New England as one of three primary regions of concern for reliability risks, alongside California and Texas.[12]

Policymakers must prioritize grid reliability when considering decarbonization policies.

Evolving Resource Mix

A profound shift in our generation mix, from primarily fossil-fuel resources to increasing reliance on zero-carbon resources, is already happening. And it is happening fast—even faster than anticipated.[13] Despite the lack of a cohesive, long-term federal climate policy,[14] the recent pace of change in the power sector has been striking.

Let's look at the numbers: According to NERC, as reported in 2021 as compared to 2020, the nameplate capacity of solar generation projects in all stages of development for the next decade increased 30 percent; the nameplate capacity of wind generation projects in all stages of development for the next decade increased 44 percent; and battery projects in interconnection queues increased 240 percent through 2024.[15] NERC also reports that year-over-year, from 2020 to 2021, confirmed retirements of coal, nuclear, and natural-gas generation resources through the year 2026 have increased by 126%.[16]

These trends are driven in part by market forces, like decreased costs associated with renewable generation and increased consumer demand for clean energy. Federal tax incentives have driven investments in variable power resources like wind and solar power. States have adopted a series of regulations, subsidies and carbon pricing regimes to reshape the generation mix.[17] Similar trends likely will continue in the coming decades, further accelerated by energy policy choices.[18] The U.S. Energy Information Administration's reference-case modelling predicts that as coal and nuclear generating units continue to retire, they will be replaced by natural gas and renewable resources, with renewable resources accounting for approximately 60% of capacity additions between 2020 and 2050.[19] Other models predict that renewable resources will make up almost 70% of grid-connected power generation by 2050, with fossil-fuel resources accounting for just 13%.[20]

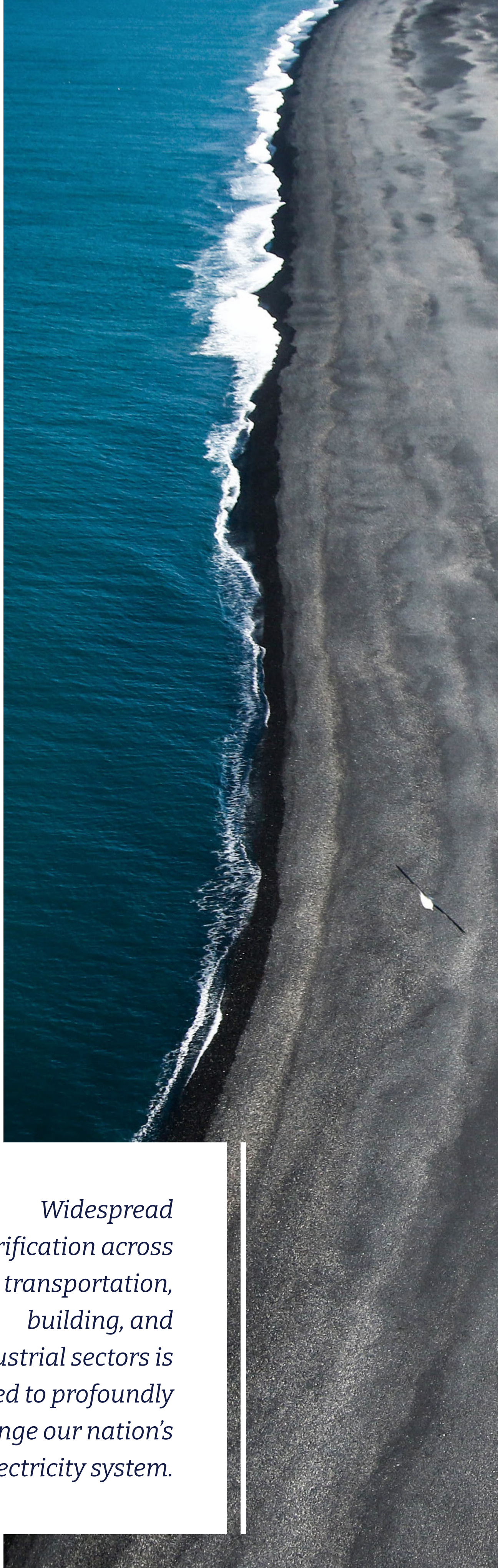
Power sector decarbonization is happening. The emerging and urgent question today is how to support and accelerate rapid decarbonization in the power sector in a manner that also best serves American families and businesses by supporting grid reliability at least cost.

Electrification

Electrification—generally defined as the substitution of electricity for fuel combustion to provide similar services[21]—is viewed by many as essential to successful decarbonization.[22] As environmental advocates and some observers call on the nation to "electrify everything," an increasing number of tools, devices, buildings, vehicles, appliances, and other energy-dependent items will begin to rely on electricity instead of other fuels. Widespread electrification across the transportation, building, and industrial sectors is poised to profoundly change our nation's electricity system.[23] The Biden Administration has adopted electrification as a central tenet of its climate policy, with the 2021 Infrastructure Investment and Jobs Act including historic investments in a national electric vehicle charging network and electric school and public transportation buses.[24] States also are leaning in to electrification. As just one example, New York recently has released a comprehensive framework for electrification in its residential, commercial, and industrial sectors.[25]

Though there are inherent difficulties in predicting how electrification will affect electricity demand, we can expect a significant rise in electricity demand—potentially doubling by midcentury[26]—and a potentially significant shift in demand profiles.[27] One grid operator has concluded that electrification could have such a profound effect that it could shift the region's peak demand from summer to winter due to the electrification of space heating systems.[28]

Electrification not only increases grid reliability pressures, but also increases the importance of remaining laser-focused on reliability, because a larger portion of our daily lives will become grid-dependent. Electrification also amplifies the importance of decarbonizing efficiently and at least cost so that increasingly grid-dependent families and businesses can make ends meet.



Widespread electrification across the transportation, building, and industrial sectors is poised to profoundly change our nation's electricity system.

The Challenge:

KEEPING RELIABILITY IN FOCUS

Converging trends require our focus on the brass tacks of grid reliability. The two primary components of grid reliability are (1) resource adequacy, which means having sufficient generation available to meet current and future demand, and (2) operating reliability, which means having tools in place to ensure the grid continuously maintains the delicate balance of real-time electricity supply and demand.

To achieve resource adequacy, the grid must have enough available generation resources to continually meet the electricity customer requirements, taking into account scheduled and expected outages.[29] As a general matter, states are responsible for ensuring resource adequacy, though myriad actors at the federal, regional, state, and local level play a role in shaping the resource mix.

To achieve operating reliability, grid operators must ensure that a diverse set of generator attributes are available day-to-day and moment-to-moment to guard against sudden disturbances such as the sudden loss of generation or transmission that lead to uncontrolled blackouts.[30] Generator reliability attributes include frequency response (the ability to stop sudden frequency changes caused by an imbalance between generation and demand), voltage control (the ability to inject or absorb reactive power to maintain system voltages), ramping (the ability to increase or decrease real power to maintain system balance), fuel assurance (the ability to maintain generator output for a duration of time due to the availability fuel), flexibility (the ability of a generator to flexibly come online and offline), and black start (the ability to independently start up in order to restart the grid after a widespread blackout).[31]

The converging forces of power-sector decarbonization, extreme weather, and electrification create new resource adequacy and operating reliability pressures. These converging forces also create new complexities for grid operators and power system planners, who must forecast future supply and demand in order to ensure the grid's ability to meet future needs.

Resource Adequacy Challenges

NERC identifies potential capacity shortfalls due to expected retirement of power plants and uncertainty that sufficient replacement capacity will come online.[32] Even where capacity-based estimates project there will be sufficient resources in the future, the reality on the ground may be more complex. NERC has emphasized that we will face resource adequacy shortfalls if variable resources are not supported by sufficient fuel-assured and weatherized dispatchable resources—resources that can be fired up quickly and reliably regardless of wind, solar, or other weather conditions.[33]

What do these challenges look like across the United States? Resource adequacy challenges vary from region to region but echo the same themes. NERC warns that in the Midwest, power plant retirements are accelerating projected capacity shortfalls, which could begin in 2024. In California, a nuclear plant retirement is exacerbating already-existing energy risks that arise from multiple factors, including resource inefficiency during widespread heat events and the temporal limitations of solar output. And in the Northwest and Southwest, quickly dispatchable resources are making up a smaller share of the resource mix and, with that trend, so is the risk of energy shortfalls.[34]

Extreme weather exacerbates these challenges because it can reduce available electricity supply and, due to factors like extreme temperatures, can push demand up beyond forecasts (which, as explained below, are becoming harder and harder to get right).[35] Extreme atmospheric conditions like smoke from wildfires that can dampen solar generation and abnormal "wind drought" can exacerbate supply uncertainty.[36] Some modelling indicates that significant reliability challenges could arise in the future during multi-day periods of reduced variable energy supply if energy storage and demand response are insufficient to balance supply and demand. Extreme weather has also impaired traditional energy resources by damaging infrastructure and freezing equipment and on-site fuel supplies, further contributing to reliability challenges.[38]

Electrification also will amplify these resource adequacy challenges. Load growth and shifting load patterns "exacerbate the flexibility challenges that renewable generation already causes on the supply-side of the grid."[39] If electrification unfolds without sufficient focus on potential reliability impacts or support for energy efficiency measures, the negative impacts of severe weather events and outages will worsen, because building heating and transportation will be grid dependent.[40]

Operating Reliability Challenges

The nation's largest grid operator has concluded that, absent reform, the increased penetration of renewable resources will lead to declines in essential reliability services available to the grid.[41] As more and more variable resources penetrate the resource mix, the need for additional flexible, dispatchable capacity on the system increases, particularly to meet increased needs for ramping, load-following, and regulation capability. Risks associated with fuel and energy assurance rise as variable resource penetration increases.[42] Inverter-based resources, like most solar and wind resources, along with new battery resources, can create reliability challenges because they respond to grid disturbances with programmed logic,[44] meaning that they can sometimes trip offline "instantaneously and erroneously," which can further exacerbate grid disturbances.[45]

Battery storage resources are zero-carbon tools capable of bolstering certain essential reliability services, including voltage support, frequency response, and system inertia, just as traditional resources do.[46] However, much more storage capacity—and much longer duration storage capacity—is required.[47] Storage resources will increasingly support operating reliability and resource adequacy. But we need to find ways to expedite the process of bringing storage online: As of the end of 2020, there were almost 200 gigawatts of storage waiting in interconnection queues,[48] as grid operators waded through the lengthy, iterative study processes that are required to bring new resources online.

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Planning and Forecasting Uncertainty

Decarbonization, extreme weather, and electrification are among the factors creating new complexity and uncertainty for grid operators and power system planners. Uncertainty arises on the supply side as more variable resources and distribution-connected resources penetrate generation portfolios. Demand-side uncertainty also persists. Extreme weather creates volatility in demand forecasting, which is of particular concern during peak demands that accompany extreme weather events.[49] Electrification is expected to lead to significant changes to electricity demand, both by increasing the total amount of annual demand and altering demand profiles, such as by yielding more pronounced daily demand peaks.[50] Uncertainty regarding the pace of electrification and advancements in demand-side technologies add to the list of "unknown unknowns" facing grid operators.[51]

The energy transition is underway and unfolding rapidly—if unevenly—across the country. Key to accomplishing the decarbonization of the U.S. electricity system is ensuring that reliability stays in focus. Practical and political challenges may impede the uptake of low-carbon and renewable resources unless policies are designed to explicitly support decarbonization, affordability, and reliability.

The energy transition is underway and unfolding rapidly—if unevenly—across the country.

The Solution:

CARBON PRICING SUPPORTS BOTH GRID RELIABILITY AND DEEP DECARBONIZATION AT LEAST COST

As the energy transition continues in full swing, policymakers must identify a pathway to continue and accelerate decarbonization while supporting grid reliability in the most efficient way possible. Enter carbon pricing. Carbon pricing is uniquely positioned to directly and efficiently address the primary cause of climate change—carbon emissions—without skewing incentives away from grid reliability. Though other policy interventions may play a role in the collective effort, an economy-wide carbon price is the optimal policy tool to advance the twin objectives of decarbonization and grid reliability at least cost.

1 | Carbon pricing values **all** emissions reductions in real time.

As we push toward the grid of the future, we must do what we can to maximize emissions reductions while supporting reliability *today*. This will require retaining existing zero-and low-carbon resources needed for reliability; creating incentives for the deployment of new renewable and other zero carbon resources; and supporting energy efficiency and demand response. Carbon pricing is the only policy tool for decarbonization that naturally (and efficiently) sends price signals to incentivize *all of these things*. Carbon pricing creates an incentive for reduced power sector emissions in real time, in every single hour of the day, no matter what form they take. This supports reliability. Here's how:

Throughout the day, grid operators and utilities must select and dispatch the set of resources capable of meeting electricity demand and reliability needs moment-to-moment, and they seek to do so with the least expensive set of resources. This is generally referred to as "economic dispatch."[52] Grid operators identify and dispatch the least expensive set of resources in the "resource stack" that can meet system needs. As demand increases, operators call on more expensive resources higher up in the resource stack.

Putting a price on carbon changes the economics of individual resources, pushing higher-emitting resources higher in the resource stack (making them relatively more expensive and less likely to be dispatched, but still available if needed) and pushing lower- and zero-carbon resources lower in the resource stack (making them relatively less expensive and more likely to be dispatched). Importantly, carbon pricing also creates a price signal to reduce demand, which affects how high up in the resource stack grid operators must reach to maintain grid reliability.

With a price on carbon embedded in economic dispatch decisions, there is a natural mechanism for grid operators to chase *all* forms of emissions reductions, regardless of why and how they arise. The grid will, in every hour of every day, lean towards the lower-carbon set of resources that can most efficiently and reliably serve demand – and will do so without the immediate need for any significant market reforms. Other decarbonization policies do not similarly embed the full suite of emissions reductions in dispatch decisions.

Carbon pricing creates incentives to retain existing clean resources and unlocks incremental emissions reductions

There are low- and zero-carbon resources operating today that are critical to both grid reliability and emissions reductions. This includes zero-carbon nuclear resources that can steadily serve demand and flexible natural gas resources that can follow shifts in load and are required to support the integration of renewables. However, some of these resources are at risk for retirement because the market does not currently and accurately value their contributions to emissions reductions and reliability. As described above, carbon pricing is a straightforward way to ensure that existing resources are dispatched (and thus compensated) for their zero- and low-emissions attributes.

In the same way, carbon pricing rewards plant owners that deploy emission-minimizing technology and make thermal efficiency improvements. Regulations and subsidies may not similarly recognize and create an incentive for these types of incremental emissions reduction. Without a carbon price to capture very real, moment-to-moment opportunities to reduce emissions, these emission reductions will be lost.

In Focus:

NUCLEAR GENERATION

Nuclear power is the most reliable source of zero-carbon electricity on our grid and is needed to reach decarbonization goals. Yet the outlook for nuclear power, in the U.S. and across the globe, has been bleak, in part because nuclear power currently faces a competitive disadvantage relative to natural gas and renewable energy, which have experienced significant cost decreases in the past 10-15 years. In the U.S., twelve nuclear power reactors have permanently closed since 2012, with more closures anticipated in the future.

A carbon price, however, would create dependable, long-term market demand for nuclear resources' low-carbon attributes. Thus a carbon price would help head-off nuclear plant closures, avoid the need for less economically efficient subsidies, and potentially displace the need for new, higher-emitting resources to enter the marketplace to support reliability.

See Mass. Inst. Tech., *The Future of Nuclear Energy in a Carbon-Constrained World* xvi (2018); Suparna Ray, Nuclear and Coal Will Account for Majority of U.S. Generating Capacity Retirements in 2021, Energy Info. Admin. (Jan. 12, 2021), https://www.eia.gov/todayinenergy/detail.php?id=46436.

Mark Holt & Phillip Brown, Cong. Rsch. Serv., R46820, *U.S. Nuclear Plant Shutdowns, State Interventions, and Policy Concerns* (2021).

Carbon pricing drives energy efficiency and demand reduction

There can be no question that the cleanest and most reliable megawatt is the one that does not need to be generated to meet demand. Energy efficiency and demand response thus are powerful tools to reduce emissions while supporting grid reliability. A carbon price sends an economic signal to improve energy efficiency and take other measures to reduce demand, especially during peak demand hours when the grid is most strained and grid operators are most likely to reach toward higher-emitting resources. Because carbon pricing helps ensure that lower-emitting resources are called on to meet demand, and higher-emitting resources are avoided when demand drops, carbon pricing amplifies the emissions reductions associated with demand reductions. As electrification unfolds across our economy, the importance of, and opportunities for, energy efficiency and demand response will grow.[53] Decarbonization policies that fail to reward efficiency and demand reductions (and instead simply reward clean generation, which may drive inefficiencies) are designed for yesterday's grid, not the grid of the future.

In Focus:

OPERATING RELIABILITY

PJM Interconnection, the regional transmission organization for much of the Mid-Atlantic, in December 2021 concluded the penetration of variable resources will lead to a decline in essential reliability services absent any reforms. Earlier studies and modeling conducted by PJM conclude that "[a] marked decrease in operational reliability was observed for portfolios with significantly increased amounts of wind and solar capacity," including reduced levels of frequency support and fuel assurance. PJM concluded that with coal and nuclear unit retirements, reliability was most supported where the "predominant" replacement resource was natural gas, which provides a broad range of generator reliability attributes.

These realities underscore that, as the grid transitions, resource-neutral policies are needed to support the near-term entry or retention of the lowest-emitting resources required to support operating reliability.

PJM Interconnection, L.L.C., *Energy Transition in PJM: Frameworks for Analysis* 2 (Dec. 15, 2021), https://pjm.com/-/media/committees-groups/committees/mrc/2021/20211215/20211215-item-09-energy-transition-in-pjm-whitepaper.ashx

PJM Interconnection, L.L.C., *PJM's Evolving Resource Mix and System Reliability* at 5, 29 (Mar. 30, 2017), https://www.pjm.com/~/media/library/reports-notices/special-reports/20170330-pjms-evolving-resource-mix-and-system-reliability.ashx

2 | Carbon pricing is technology- and location-neutral.

Carbon pricing does not favor one type of emissions reduction over another type of reduction, which means that it does not favor specific resource types or specific resource locations. Rather, carbon pricing creates a price signal to promote investment in the diverse set of resources and infrastructure that have the most value: namely, those that are needed to serve demand and that also are associated with the highest level of emissions reductions. For this reason, carbon pricing emerges as the superior policy tool to both decarbonize the power sector and systematically support reliability at least cost.[54]

Other policies based on subsidies or regulation may contribute to achieving policy goals like the development of more renewable resources. But unlike carbon pricing—which *also* creates a strong incentive to increase the level of renewable resources—such policies could over time become out of step with the goal of efficiently supporting reliability.

For example, federal tax credits for renewable energy may steer investment dollars toward new variable resources in the geographic regions where they are most cost-effective to develop.[56] And renewable portfolio standard (RPS) programs may steer investment dollars toward new variable renewable resources located in specific states.[56] But such policies may fail to account for other factors adequately, like whether such new resources are sited near customer load or are located in areas with *already*-high levels of variable resource penetration.[57] These factors can affect whether new variable resources efficiently support grid reliability. When new generation sources are built far away from customer load, infrastructure uncertainty and costs follow, potentially straining the grid's ability to deliver power to load in the absence of new grid upgrades.[58] And when variable resources are built in locations that already feature high levels of penetration, the ability of new variable resources to contribute to grid reliability (and incremental decarbonization) may be diminished. A methodology called Effective Load Carrying Capacity (ELCC) illustrates this phenomenon.

Grid operators and planners use ELCC to evaluate the ability of a resource to contribute to resource adequacy, *i.e.,* its ability to produce electricity during periods when the grid is likely to experience a shortfall.[59] Generally speaking, as the level of one type of variable resource increases in a region, new resources of that type have a decreased ability to support reliability.[60] The oft-discussed solar "duck curve" is a common reference point. The duck curve refers to the shape of net customer demand that arises in regions where there are high levels of solar penetration.[61] Throughout the day, as the sun rises and solar output increases, there is a steep decline in net demand; as the sun sets at the end of the day—when demand naturally rises—there is a steep increase in net demand. This spike in demand cannot be met by additional solar resources.[62]

In Focus:

THE DUCK CURVE AND RELIABILITY

"The very first solar power plant you add to the grid is a reliability rockstar, tackling daytime reliability shortfalls with ease. But as you add more and more solar plants that are all producing electricity at the same time, it reaches a point where all those solar plants are preventing daytime reliability issues so effectively that the remaining reliability challenges move into the evening hours when solar can't help. At this point, adding more solar does very little to prevent electricity shortages."

Mark Specht, Union of Concerned Scientists, *ELCC Explained: The Critical Renewable Energy Concept You've Never Heard Of* (Oct. 12, 2020), https://blog.ucsusa.org/mark-specht/elcc-explained-the-critical-renewable energy-concept-youve-never-heard-of/

This is more than just a resource adequacy challenge; it is an emissions-reduction challenge. Only those low- and zero-carbon resources that can contribute to grid reliability can displace the higher-emitting resources that are needed for reliability. Policies that are bluntly designed to promote specific resource types, sometimes in specific locations, are not calibrated to efficiently support both emissions reductions and reliability over time. Modelling has shown that prescriptive policies like RPS become less cost-effective relative to neutral policies like carbon pricing as we reach for deeper cuts in emissions.[63]

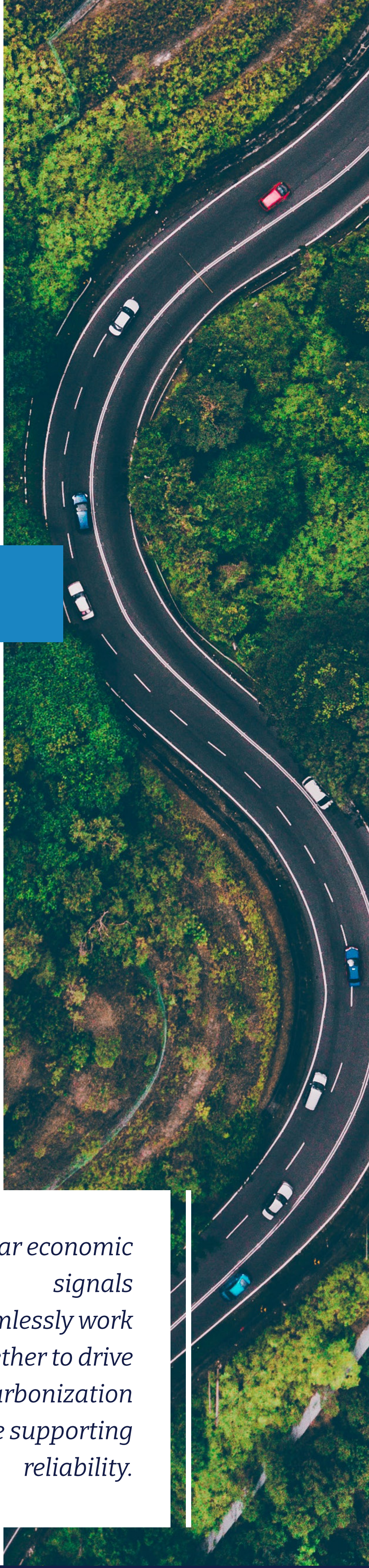
To be clear, the decarbonization of our economy requires the deployment of substantially more renewable resources. We won't get there without them. The key is bringing these resources online in the most efficient way that also ensures grid reliability.

3 | Carbon pricing sends price signals that work together to drive emissions reductions and support reliability.

As detailed above, carbon pricing sends a price signal to avoid emissions; it is also added to the existing price signal to serve energy demand where and when it is needed (or, alternatively, to reduce demand). These clear economic signals seamlessly work together to drive decarbonization while supporting reliability. Other decarbonization policies effectively separate the price signals for reducing emissions and meeting customer demand, creating opportunities for those price signals to work at cross purposes, driving down efficiencies.

In hours where variable resources cannot meet demand, grid operators must lean on a variety of resources and tools to manage the steep shifts in net demand and avoid strains on the grid. As we decarbonize, this will require an economic signal to support, among other things, a diverse resource mix[64] with broadly-deployed storage technologies, robust demand response, and increased grid interconnectedness. Carbon pricing sends a neutral price signal to support all of these tools in the locations where they are needed. And when variable resources cannot adequately meet demand, grid operators should have an economic signal to draw from the lowest-carbon energy mix available (e.g., by dispatching natural gas—potentially with carbon capture technology—before dispatching a traditional coal resource). Carbon pricing provides that economic signal.

Carbon pricing stands apart as the policy tool that sends clear price signals that work together to drive decarbonization while supporting reliability.



Clear economic signals seamlessly work together to drive decarbonization while supporting reliability.

4 | Carbon pricing supports infrastructure, innovation, and market reforms.

The clean and reliable grid of the future will require significant investment and forward thinking. Carbon pricing paves the path to the future by injecting clarity and predictability into long-term infrastructure planning, research and development processes, and market reforms.

Globally, the clean energy transition will demand new generation capacity, an expanded and modernized transmission and distribution system, and expanded storage resources, at an estimated price tag of $4 trillion by 2030 and more than $100 trillion when all is said and done.[65] In the U.S., some estimates show that in the next eight years, between now and 2030, we need to quadruple wind and solar electricity generating capacity, and in concert, expand our high-voltage transmission capacity by 60% to connect the renewable electricity with load centers.[66] Bolstering grid interconnectedness is critical. The fact that the isolated Texas grid went dark in February 2021, while more interconnected portions of the grid did not, paints a stark picture.[67]

Despite the urgent need to invest in long-lived power-sector assets, long-term resource and infrastructure planning is becoming more and more complex.[68] Grid planners, system operators, and investors need predictable data to project supply and demand trends and identify where and when infrastructure investments are needed to serve demand in future years. One grid operator has explained that when variable generation begins serving more than 30% of annual load, successful transmission planning and expansion requires "transformative thinking."[69] Federal legislation to implement an economy-wide carbon price with a clear long-term trajectory would deliver the data and predictability needed to support transformative thinking.

An economy-wide carbon price is built for the long-term and can begin shaping long-term investment decisions immediately. Emerging and new innovative resources will compete to maintain reliability in a

> *The resource mix in the future will have complex and evolving carbon emission and reliability profiles. Carbon pricing will allow these technologies to compete on a level playing field.*

deeply decarbonized grid. The resource mix in the future will have complex and evolving carbon emission and reliability profiles. Carbon pricing will allow these technologies to compete on a level playing field. Other regulatory pathways that rely on federal agency implementation may overlook decarbonization and reliability benefits, and be subject to delays, partisan programmatic shifts, and protracted litigation.

Organized market reforms also require data and predictability. As zero-marginal-cost renewable resources make up a larger share of the marketplace and are increasingly dispatched to serve demand, pushing down market clearing prices to sometimes negative levels, organized market structures will need to evolve. In particular, market reforms will be needed to improve price formation so that organized markets can more accurately and transparently value the reliability attributes provided by flexible resources.[70] However, meaningful market reforms require a stable policy environment. If policies to address carbon emissions frequently shift, and if state- and federal-level policies conflict, meaningful market reforms are harder to achieve. A stable price on carbon would diffuse these challenges.

5 | Carbon pricing is an economy-wide solution

We cannot decarbonize the U.S. economy through the electricity sector alone. The electricity sector accounts for only about one-quarter of greenhouse gas emissions across our economy, with the transportation, building, and industrial sectors also playing a large role in emissions.[71] Economy-wide carbon pricing reaches all sectors.

Deep decarbonization likely will depend on multi-sector electrification, which carbon pricing can help unleash and maximize. A 2018 report by the Electric Power Research Institute studied electrification in a future scenario in which a carbon price is implemented and found that a carbon price amplified the benefits from electrification.[72] This is not only because carbon pricing shapes the generation mix to be less carbon-intensive,[73] but also because carbon pricing actually drives toward a more rapid expansion of electrification.[74]

Fundamentally, economy-wide carbon pricing supports both deep decarbonization and grid reliability because it spurs emissions reductions across all sectors not just the power sector. It will rapidly achieve the least-cost emissions reductions first, in whichever segment of the economy they occur. This is key because reliability experts have been clear that moving to a zero-carbon power grid is a long-term goal rather than a near-term possibility. Economy-wide carbon-pricing thus helps create a runway for the steady decarbonization retrofit or replacement of the carbon-emitting resources that currently are needed to support grid reliability as we lean more heavily on our grid. Phasing out power sector emissions rapidly and reliably is the goal; carbon pricing is the pathway.

There are a number of other benefits of carbon pricing that make it particularly well-suited for the U.S. economy. Carbon pricing can raise hundreds of billions of dollars in revenue that can be distributed to households ensuring the majority of Americans see an *increase* in household income from climate policy.[75] Additionally, a carbon price is easily pared with a border carbon adjustment, which not only ensures a level playing field for American businesses, but a *competitive advantage* for those domestic firms that are more carbon efficient than their less efficient overseas competitors.[76]

Deep decarbonization likely will depend on multi-sector electrification, which carbon pricing can help unleash and maximize.

THE TIME FOR CARBON PRICING IS NOW.

Reliable, affordable electricity is vital to our economy, our daily lives, and the health and safety of Americans. In this moment, extreme weather, power sector decarbonization, and electrification, among other forces, are converging to create unprecedented tests for our grid. Grid reliability must remain sharply in focus as we decarbonize. Carbon pricing is the optimal federal legislative pathway to achieve both reliability at least cost and deep decarbonization.

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ABOUT THE CLIMATE LEADERSHIP COUNCIL

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The Climate Leadership Council is a research and policy organization founded in 2017 to promote effective, fair, and lasting climate solutions based a carbon dividends framework. Learn more at www.clcouncil.org

This report is a work product of the Climate Leadership Council and does not necessarily reflect the views of its organizational partners.

NOTES

1. N. Am. Elec. *Reliability Corp., 2021 Long-Term Reliability Assessment* 5 (2021) ("NERC LTRA") ("Governmental policies, changes in comparative resource economics, and customer demand for clean energy are driving the rapidly changing resource mix within the BPS; the BPS has already seen a great deal of change and more is underway. Managing this pace of change presents the greatest challenge to reliability.").

2. The Baker Shultz Carbon Dividends Plan would return all net revenue raised by the carbon fee to American families in the form of per capita dividends. For more information on the plan and its impact to families, visit clcouncil.org

3. Nat'l Oceanic and Atmospheric Admin., *Billion-Dollar Weather and Climate Disasters*, https://www.ncdc.noaa.gov/billions/overview (last visited Jan. 13, 2022).

4. Fed. Energy Reg. Comm'n and N. Am. Elec. Reliability Corp., *The February 2021 Cold Weather Outages in Texas and the South Central United States* 15 (2021).

5. Comptroller of the State of Texas, October 2021 Fiscal Notes: Winter Storm Uri 2021, https://comptroller.texas.gov/economy/fiscal-notes/2021/oct/winter-storm-impact.php.

6. Kavya Balaraman, *"Imagine the Unimaginable": How the Pacific Northwest Is Trying to Build a Reliable Grid in a Changing Climate*, Utility Dive (Nov. 8, 2021), https://www.utilitydive.com/news/pacific-northwest-reliable-grid-changing-climate/608959/.

7. John Ryan, 2021 *Heat Wave is Now the Deadliest Weather-related Event in Washington History*, Nat'l Pub. Radio (July 19, 2021, https://www.kuow.org/stories/heat-wave-death-toll-in-washington-state-jumps-to-112-people.

8. *See generally* Cal. Indep. Sys. Op., Cal. Pub. Utils. Comm'n, & Cal. Energy Comm'n, *Preliminary Root Cause Analysis: Mid-August 2020 Heat Storm* (2020).

9. *PG&E Will Bury 10,000 Miles of Power Lines so They Don't Spark Wildfires*, Nat'l Pub. Radio (July 21, 2021), https://www.npr.org/2021/07/21/1019058925/utility-bury-power-lines-wildfires-california.

10. N. Am. Elec. Reliability Corp., *Polar Vortex Review* 8 (2014).

11. ISO New England Inc., Pre-Technical Conference Comments, Fed. Energy Reg. Comm'n Docket No. AD21-13, at 2 (filed Apr. 15, 2021).

12. *Power Struggle: Examining the 2021 Texas Grid Failure: Hearing Before the Subcomm. On Oversight and Investigations of the H. Comm. on Energy and Com.,* 117th Cong. 6-7 (2021) (testimony of James B. Robb, President and CEO, N. Am. Reliability Corp.).

13. *See, e.g.,* Rupert Way et al., *Empirically Grounded Technology Forecasts and the Energy Transition* (2021) (study suggesting that cost savings from the energy transition are themselves accelerating the energy transition); Kingsmill Bond, Int'l Renewable Energy Agency, *The Renewable Spring: The Interplay Between Finance and Policy in the Energy Transition* (2021) (showing how capital markets continue to reward new energy technology in a way that outperforms much of the rest of the market, in a sign that the transition will continue to accelerate); *see also id.* at 14 ("COVID has likely brought forward the moment of overall peak fossil fuel demand to 2019 because it has damaged demand for fossil fuels but not held back the growth of renewables.").

14. The Biden Administration has staked a goal of zero carbon pollution in the power sector by 2035 and net-zero emissions economy-wide by 2050. *President Biden's Whole-of-Government Effort to Tackle the Climate Crisis,* The White House, Nat'l Climate Task Force, https://www.whitehouse.gov/climate/. However, recent decades have been marked by an absence of a durable, bi-partisan federal climate policy.

15. NERC LTRA at 29.

16. *Id.* at 35.

17. *See* Advanced Energy Economy, Prepared Remarks of Jeff Dennis, Fed. Energy Reg. Comm'n Docket No. AD21-12-000 (describing myriad state clean energy policies); *U.S. State Carbon Pricing Policies, Ctr.* For Climate & Energy Sols. (May 2021), https://www.c2es.org/document/us-state-carbon-pricing-policies/.

18. Robert Walton, *Biden Decarbonization Goals Could Triple Reliance on Electric Grid: EPRI,* Utility Dive (Jan. 14, 2022), https://www.utilitydive.com/news/biden-decarbonization-goals-could-triple-reliance-on-electricity-grid-epri/617188/ (citing expert projections that electricity's share of end-use energy consumption in the U.S. could rise to 60% by 2050–from the current 20%--and that this will need to be met by the addition of significant new capacity to the grid).

19. Energy Info. Admin., *Annual Energy Outlook 2021* 16 (2021).

20. DNV, *Energy Transition Outlook 2021* 4 (2021), https://eto.dnv.com/2021/about-energy-transition-outlook. The report also predicts that fossil fuels will retain 50% of the overall energy mix, with renewables accounting for the other 50%. Id. At 5.

21. *See* Nat'l Renewable Energy Lab'y, *Electrification Futures Study: Operational Analysis of U.S. Power Systems with Increased Electrification and Demand-Side Flexibility* iv (2021) ("Electrification Futures Study").

22. *See,* e.g. Caitlin Murphy, et al., *High electrification futures: Impacts to the U.S. Bulk Power System,* The Electricity J. 33 (2020) ("[E]conomic potential estimates that are rooted in energy system decarbonization (e.g., with a carbon price) often include significant shares of electrification."); Midcontinent Indep. Sys. Op., *2021 MISO Transmission Expansion Planning* 9 (2021) ("[C]ustomer, utility and state efforts to decarbonize will employ increasing electrification of the economy as an important tool to meet those goals.").

23. Electrification Futures Study, *supra* note 21, at 1.

24. *Fact Sheet: The Bipartisan Infrastructure Deal,* The White House (Nov. 6, 2021)https://www.whitehouse.gov/briefing-room/statements-releases/2021/11/06/fact-sheet-the-bipartisan-infrastructure-deal/.

25. New York State Climate Action Council, *Draft Scoping Plan* 264 (2021) ("Under all scenarios, the vast majority of current fossil gas customers (residential, commercial, and industrial) will transition to electricity by 2050.").

26. The White House, *United States Mid-Century Strategy for Deep Decarbonization* 30 (2016) (projecting an increase in electricity generation of between 60 to 113 percent between 2005 and 2050); Electric Power Research Institute, *U.S. National Electrification Assessment* 7 (2018) ("With efficient electrification, the study projects cumulative load growth of 24% by 2050" compared to 2015 levels, with the higher end of the spectrum resulting in the event of the widespread adoption of carbon pricing) ("EPRI Report").

27. Midcontinent Indep. Sys. Op., *MISO Electrification Insights* 27 (2021) ("MISO Electrification Insights").

28. *Id.*

29. NERC LTRA, *supra note* 1, at 11.

30. *See* id.

31. *See generally* PJM Interconnection, L.L.C., *Reliability in PJM: Today and Tomorrow* 4-6 (Mar. 11, 2021), https://pjm.com/-/media/library/reports-notices/special-reports/2021/20210311-reliability-in-pjm-today-and-tomorrow.ashx; PJM Interconnection, L.L.C., *Energy Transition in PJM: Frameworks for Analysis* 13-18 (Dec. 15, 2021) ("PJM Frameworks"), https://pjm.com/-/media/committees-groups/committees/mrc/2021/20211215/20211215-item-09-energy-transition-in-pjm-whitepaper.ashx (both generally describing reliability attributes).

32. *See* NERC LTRA, *supra* note 1, at 5-9 (explaining that "[c]apacity shortfalls, where they are projected, are the result of future generator retirements that have yet to be replaced with new resource capacity," and detailing regional findings); *see also generally* Nat'l Ass'n Regul. Util. Comm'ns, Resource Adequacy Primer for State Regulators (July 2021) ("NARUC Primer"); *id*. at 60 ("The evolving resource mix throughout the country – particularly in areas such as California – can impact the timing of the net peak and create challenges in maintaining system reliability. . . . Ensuring that there are sufficient resources available to serve load during the net peak period and other potential periods of system strain could require more comprehensive resource adequacy analysis.").

33. NERC LTRA, *supra* note 1, at 5 ("Capacity-based estimates, however, can give a false indication of resource adequacy. Energy risks emerge when variable energy resources (VER) like wind and solar are not supported by flexible resources that include sufficient dispatchable, fuel-assured, and weatherized generation.").

34. *Id.*

35. NERC LTRA, *supra* note 1, at 23; see NARUC Primer, *supra* note 32, at 60 ("[F]orecasting electricity usage (or demand) has become more complicated due to changing load profiles, behind-the-meter resources, and increasing occurrences of extreme weather events.").

36. *See* NERC LTRA, *supra* note 1, at 6.

37. Energy & Env't Econ., *Net-Zero New England: Ensuring Electric Reliability in a Low-Carbon Future at 43* (Nov. 2020); *see also* NERC LTRA, *supra* note 1, at 6 ("Wide-area and long duration extreme weather events driven by climate change threaten reliability when electricity demand is driven above forecasts and supplies are reduced. Diminished levels of flexible generation--fuel-assured, weatherized, and dispatchable resources--create vulnerabilities to energy shortfalls when extremely hot or cold weather settles over a wide area for extended duration or when weather-dependent generation is impacted by abnormal atmospheric conditions, such as smoke or wind drought…").——

38. Fed. Energy Reg. Comm'n and N. Am. Elec. Reliability Corp., *The February 2021 Cold Weather Outages in Texas and the South Central United States* 167-172 (2021) (detailing how freezing issues and fuel issues across all resource types caused "75.6 percent of the 4,124 total unplanned generating unit outages, derates, and failures to start" during the February 2021 cold weather event in Texas and the South Central United States).

39. MISO Electrification Insights, *supra* note 27, at 7.

40. *See id*. at 9.

41. PJM Interconnection, L.L.C., PJM Frameworks, *supra* note 31, at 2; see also *S. Cal. Edison, Reimagining the Grid* at 1 (Nov. 2020) ("The growth of inverter-based resources (i.e., solar, wind, storage) to replace conventional generation will lead to loss of system inertia and other grid services that ensure system reliability today.").

42. N. Am. Elec. Reliability Corp. & Cal. Indep. Sys. Op. Corp., *2013 Special Reliability Assessment: Maintaining Bulk Power System Reliability While Integrating Variable Energy Resources – CAISO Approach* 13 (2013).

43. PJM Interconnection, L.L.C., PJM Frameworks, *supra* note 31, at 17.

44. 2021 NERC LTRA, *supra* note 1, at 6.

45. *See generally* Sandia Laboratories, *Momentary Cessation: Improving Dynamic Performance and Modeling of Utility-Scale Inverter Based Resources During Grid Disturbances* 11 (January 2020), https://www.osti.gov/servlets/purl/1593544.

46. 2021 NERC LTRA, *supra* note 1, at 39.

47. *See, e.g.,* Julian Spector, *Pumped Hydro Grid Storage Could be Poised for a Comeback,* Canary Media (Jan. 25. 2022), https://www.canarymedia.com/articles/long-duration-energy-storage/pumped-hydro-grid-storage-could-be-poised-for-a-comeback.

48. Lawrence Berkeley Nat'l Lab'y, *Queued Up: Characteristics of Power Plants Seeking Transmission Interconnection as of the End of 2020* (2021). Because storage is a limited-duration resource, as more and more storage resources come online, their marginal contribution to resource adequacy also declines. Energy + Env't Econ., *Capacity and Reliability Planning in the Era of Decarbonization: Practical Application of Effective Load Carrying Capability in Resource Adequacy* 5 (2020).

49. *See* 2021 NERC LTRA, *supra* note 1 at 8, 23.

50. Electrification Futures Study, *supra* note 21, at 1.

51. *See* MISO Electrification Insights, *supra* note 27, at 49; *see* also NARUC Primer, *supra* note 32, at 60 ("Some have questioned if traditional load forecasting methods based on historic averages of seasonal extremes capture these trends and the ongoing electrification of space and water heating.").

52. For a helpful primer on economic dispatch in the organized market context, see ISO-NE, How Resources Are Selected and Prices Are Set in the Wholesale Energy Markets, https://www.iso-ne.com/about/what-we-do/in-depth/how-resources-are-selected-and-prices-are-set.

53. *See* Electrification Futures Study, *supra* note 21, at 7-8 (discussing demand-side flexibility); *The White House, United States Mid-Century Strategy for Deep Decarbonization* 30 (2016).

54. A clean energy standard, such as one that values incremental emissions reductions, can potentially come close to the efficacy of a carbon price if properly designed. *See* Energy+Environmental Economics, Least Cost Carbon Reduction Policies in PJM at 8 (Oct. 28, 2020) ("E3 PJM Paper"), https://epsa.org/wp-content/uploads/2020/10/E3-Least_Cost_Carbon_Reduction_Policies_in_PJM-FINAL.pdf.

55. As one example, in 2019, The U.S. Energy Information Administration (EIA) reported that over half of U.S. wind capacity is located in just four states—Texas, Oklahoma, Iowa, and Kansas—in part because it is relatively cost-effective to site wind projects in these wind-rich states. EIA, Today in Energy, Four states account for more than half of U.S. wind electricity

generation (June 7, 2019), https://www.eia.gov/todayinenergy/detail.php?id=39772. Yet these states account for less than 16% percent of U.S. electricity demand. *State Electricity Profiles,* Energy Info. Admin. (Nov. 4, 2021), https://www.eia.gov/electricity/state/.

56. E3 PJM Paper, *supra* note 54, at 13 (explaining that some state policies "require development in specific geographic areas, even if the resources in those areas are more costly than resources in other locations").

57. See S. Cal. Edison, *supra* note 41, at 5 ("[H]igh-load density relative to local supply capacity, as well as limited land availability, will make it challenging to build sufficient clean resources close to load to meet peak customer demand.").

58. *See id.* at 1 ("Since the bulk of future renewable resources will be located far from customers, the uncertainty and cost of building transmission lines may stretch the grid's ability to deliver power to urban load centers.").

59. ELCC relies on loss-of-load probability modeling, which simulates the electricity system under various load and resource conditions to project expected reliability events on a system with a given portfolio of resources. ELCC is a "method to express the capacity contribution of intermittent and energy-limited resources in terms of equivalent 'perfect' capacity (capacity that is always available). In this respect, ELCC is technology-agnostic: a system with a given quantity of ELCC megawatts will achieve the same level of reliability, regardless of what types of resources are providing those megawatts." Energy + Env't Econ., *Capacity and Reliability Planning in the Era of Decarbonization: Practical Application of Effective Load Carrying Capability in Resource Adequacy* 4 (2020).

60. Mark Specht, Union of Concerned Scientists, ELCC Explained: The Critical Renewable Energy Concept You've Never Heard Of (Oct. 12, 2020), https://blog.ucsusa.org/mark-specht/elcc-explained-the-critical-renewable-energy-concept-youve-never-heard-of/ ("[]he quantity of a resource affects its own ELCC. For example, holding all other variables constant, as you add more solar to the grid, the ELCC of that solar goes down.").

61. Because solar resources are not dispatchable, they are often modelled as an offset to demand.

62. *See generally* David Roberts, Solar Power's *Greatest Challenge Was Discovered 10 Years Ago. It Looks Like a Duck,* Vox (Aug. 29, 2019), https://www.vox.com/energy-and-environment/2018/3/20/17128478/solar-duck-curve-nrel-researcher

63. E3 PJM Paper at 54 (arguing that "[p]rescriptive policy mechanisms, such as RPS policies, will become less and less cost-effective as policy targets reach higher levels" revealing the "significant value in more technology-neutral approaches").

64. Specht *supra* note 60 (explaining that "different types of generating resources interact with each other and create 'diversity benefits' that can boost ELCC values").

65. *See* Int'l Energy Agency, *Net Zero by 2050 83 (2021); see also David Carlin, The $100 Trillion Investment Opportunity In The Climate Transformation,* Forbes (June 2, 2021), https://www.forbes.com/sites/davidcarlin/2021/06/02/the-ieas-net-zero-climate-pathway-is-a-100-trillion-investment-opportunity/?sh=5e1978b45597.

66. Eric Larson et al., Princeton University, *Net-Zero America: Potential Pathways, infrastructure, and impacts (Interim Report)* 14 (Dec. 15, 2020).

67. Joshua W. Busby et al., *Cascading Risks: Understanding the 2021 Winter Blackout in Texas,* 77 Energy Rsch. & Soc. Sci. at 7 (2021) ("It is worth examining whether additional regional interconnections could potentially compensate for production shortfalls in the state and enhance the system's overall resilience. Most of the time, Texas would likely be able to sell excess power from its rapidly growing renewables capacity to other states, which implies that there might be significant economic benefits to interconnection along with resilience benefits. Several cities in Texas . . . suffered little or no power outages during the 2021 freeze in part because they are not part of ERCOT and are connected to other grids.").

68. See *supra* notes 49-51 and accompanying text (describing current planning challenges).

69. Midcontinent Indep. Sys. Operator, *MISO's Renewable Integration Impact Assessment* 4 (Feb. 2021), https://cdn.misoenergy.org/RIIA%20Summary%20Report520051.pdf ("Beyond 30%, transformative thinking and coordinated action between MISO and its members are required to prepare for the significant challenges that arise" with respect to transmission expansion, operations, market, and planning practices).

70. *See* PJM Interconnection, L.L.C., PJM Frameworks, *supra* note 31 at 2 ("[A]dding zero-marginal-cost renewable resources decreased the average locational marginal pricing (LMP) in all scenarios . . . . The study underscored the need for PJM and stakeholders to continue to work on price formation initiatives to ensure that the flexibility needs of the system are transparently priced in the market.").

71. *See Sources of Greenhouse Gas Emissions,* Env't Prot. Agency, https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions (last visited Feb. 17, 2022).

72. EPRI Report, *supra* note 26, at 5.

73. *See id.* at 42 (explaining that in the scenarios that assume a carbon price "the electric generation portfolio becomes less carbon-intensive").

74. *See id.* at 38 (explaining that the scenario with the highest assumed carbon price shows "substantial additional electrification in both buildings and industry").

75. Oxford Economics, *National & State Level Household Income Distributional Analysis of Baker-Shultz Carbon Dividends Plan*, The Climate Leadership Council, September 2020, https://clcouncil.org/report/oxford-economics-analysis/

76. CRU International, Ltd., *Leveraging a Carbon Advantage: Impacts of a Border Carbon Adjustment and Carbon Fee on the US Steel Industry*, The Climate Leadership Council, May 2021. https://clcouncil.org/report/leveraging-a-carbon-advantage/