Implications of Fully Decarbonizing the Electric Industry for Business: Icarus or Daedalus?

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Introduction and Summary

For more than a century, the U.S. electric industry has been a large, complex, and regionally varied sector of the nation's economy. And now, a large and growing number of businesses, policy and other observers see the electric industry as a foundational element of what is likely to be a decades-long transition to a fully decarbonized economy-wide energy system. This energy transition presents unprecedented investment opportunities for companies in the U.S. electric sector, as well as large management challenges and financial risks.

The previous chapter of this book, "The Patchwork Quilt: Business Complexities of Decarbonizing the Electric Sector," reviewed the varying economic, technology and policy dynamics in the electric sector, focusing on the industry's recent history and current structure. This chapter builds on that by taking a longer-term view, examining the scale of new energy infrastructure needed to achieve a fully decarbonized economy-wide energy system and the unprecedented investment opportunities and challenges this presents for businesses in the electric sector.

Over the next several decades, the energy transition will entail replacing or decarbonizing nearly all of today's carbon-emitting fossil generation which still provides roughly 60 percent of all U.S. electric energy. It is also expected to require a doubling of electric generation and a tripling of electric capacity. Even after realizing the savings from ambitious energy efficiency programs, this expansion will be needed to electrify and decarbonize portions of the transportation, industry, and space conditioning sectors of the economy. The resiliency of electric infrastructure will also need to be improved to withstand what most climate scientists expect to be increasingly frequent and severe weather events.

At the same time, the form and timing of the energy transition is unknown due to persistent and intrinsic uncertainties with federal and state climate and energy policy, the pace and scale at which new clean energy infrastructure will be deployed, and long-term evolution of low-carbon technology pathways. These uncertainties are compounded, as detailed in the previous chapter, by the complex regional complex "patchwork quilt" of natural resource endowments, economic conditions, regulatory systems, and policy priorities currently across the U.S.

For companies in the electric industry, the energy transition and its uncertainties point to three broad types of business challenges.

1. Deploying Commercial Technologies at Scale. The first challenge is how to rapidly scale the deployment of carbon-free technologies that have already been largely commercialized in some regions of the country such as wind, solar and batteries. This is likely to rest on a mix of new government policies and business initiatives including federal or state policies to "pull" these technologies into the marketplace, transmission policy reforms, new financing structures and business models, expanded supply chains, and reformed corporate practices and government policies to speed siting and permitting.

2. Commercializing Advanced Technologies. The second business challenge is how to demonstrate and commercialize advanced clean energy technologies such as carbon capture, zero-carbon liquid fuels, advanced nuclear and firm renewables, which are likely to be needed to fully decarbonize the economy in a reliable and affordable way. To be successful, these technologies will need to achieve technical milestones and economic benchmarks established by competing clean energy technologies, recognizing how each will operate in an integrated electric system. Given the large capital costs, timeframes and risks involved, patient financing from both the private and public sectors will likely be needed.

3. Managing Existing Generation Fleets. The third challenge is how to manage the existing electric generating fleets: whether to secure financial support for marginally economic nuclear plants or plan their retirement and decommissioning; whether to retrofit coal plants with carbon capture equipment or plan for their retirement; and whether to retrofit gas plants with carbon capture equipment, retire them, or maintain them primarily as low-utilization resources to balance the variability of wind and solar output and provide electric system reliability.

To address these challenges, businesses will need strategic foresight, financial resources, and prudent risk management. The ability to manage commercial and organizational risks arising from uncertain government policies, technology competitiveness, and deployment forces will be a core competency.

The remainder of this chapter is structured around the following sections:

1. Rapidly Growing Support for the Energy Transition
2. Recent Technology, Policy and Emission Trends in the U.S. Electric Industry
3. Growth Opportunities for the Electric Industry
4. Uncertainties in the Energy Transition
5. Implications for Electric Businesses and Decision Making

Rapidly Growing Support for the Energy Transition

A large and growing number of policymakers, business leaders and industry analysts see the electric industry as being in the initial stages of an economy-wide transition to a cleaner, fully decarbonized energy system that will also be more resilient in the face of what most climate scientists expect to be increasingly frequent flooding, wildfires and extreme storms. These and other impacts of climate change have been examined in a series of widely reported and closely examined reports issued by the Intergovernmental Panel on Climate Change (IPCC), the most recent of which as of this writing was released in August of 2021. (IPCC, 2021) These developments have led to the adoption of various policy and corporate goals such as limiting global warming to a level between 1.5 degrees Celsius and 2.0 degrees Celsius above preindustrial levels and achieving "net-zero" greenhouse gas emissions by mid-century.

The electric sector is typically seen as a foundational element of this energy transition because of its large carbon footprint, the availability of proven and relatively low-cost zero-carbon generating technologies, and the opportunity to rely on the electric sector to decarbonize other sectors of the economy. This will fundamentally transform the electric sector over the coming decades and present both unprecedented growth opportunities and investment risks that will need careful management.

In the years leading up to 2021, dozens of states, electric utilities and other corporations in the U.S. responded to growing concerns over climate change impacts and the economic opportunities stemming from clean energy deployment by adopting ambitious clean energy and carbon emission reduction goals.

Building on numerous state Renewable Portfolio Standard (RPS) policies, these include, as of early 2021, 11 states with 100 percent clean energy or net-zero carbon emission goals and 29 electric utilities with pledges to reduce carbon emissions by 80 percent to 100 percent relative to historic levels. These states and utilities are distributed widely across the country including not only the two coasts, but also many entities in the Southwest, Midwest and Southeast regions. (Place, 2020)

Beyond the state level, the Regional Greenhouse Gas Initiative (RGGI), a market-based cap-and-trade program covering the electric sector in 11 states, has continued to expand its geographic coverage as new states join the program. (RGGI, 2021) Another example of regional action is the Transportation and Climate Initiative (TCI), which is a regional collaboration of Northeast and Mid-Atlantic states and the District of Columbia, established to reduce carbon emissions from the transportation sector. (TCI, 2021)

In the private sector worldwide, over 260 corporations, mostly outside of the electric sector, have committed to procuring their electric requirements from zero-carbon sources. (RE100, 2020) And in the U.S., in 2019, 100 major corporations from the consumer products, high technology, raw material, and heavy industry sectors procured over 20 million megawatt hours (MWh) of renewable energy, which represents more than 60 percent of their electricity consumption. (RE100, 2021) This includes roughly 10 GW of new capacity in 2020, which is about one third of the total amount of new generating capacity installed nationally in that year. Further, a growing number of major U.S. and international financial institutions including BlackRock, Morgan Stanley, Barclays, TD Bank, Citigroup, and Bank of America have announced goals to achieve net-zero greenhouse gas emissions in their operations and financing activities.

As discussed in more detail later in this chapter, fully or nearly decarbonizing the U.S. electric sector will require fundamental changes to the electric industry and a dramatic, unprecedented expansion of sector infrastructure. At a minimum, it will require decarbonizing or replacing essentially all of today's coal and natural gas-fired electric generation, which represents more than half of the nation's electric energy and generating capacity. It would further entail substantially expanding the electric sector to supply the zero-carbon energy needed to electrify non-electric sectors of the economy as will be described later.

These state and private sector efforts are very unlikely, by themselves, to lead directly to full decarbonization of the U.S. economy by about mid-century; supportive federal policies will also be required to achieve that goal. But the growing number and diversity of state and private sector efforts, along with the increasing commercial competitiveness of zero-carbon generating technologies, suggests that the U.S. electric sector will continue to reduce its carbon emissions over time and improve the resiliency of its infrastructure.

Recent Technology, Policy and Emission Trends in the U.S. Electric Industry

National trends in the electric industry, including technology deployment, fuel prices, federal and state policies, generation mix, and emissions, along with how these differ across the U.S., provide important context for the prospects and risk of the energy transition.

Since the mid- to late-2000s, carbon emissions from the U.S. electric sector have been declining, and as of 2019 (the last year before the pandemic reduced electric demands), electric sector carbon emissions were 33 percent below 2005 levels. (U.S. Energy Information Administration, 2020) While this reduction is well short of that needed to achieve many ambitious climate goals, such as net-zero, it is nonetheless a substantial decline relative to historic levels and the downward trend is relevant going forward.

The reduction in electric sector carbon emissions has been primarily driven by a shift in the mix of electric generation (with low- or zero carbon generation displacing higher carbon emitting coal generation) and greater energy efficiency. According to one analysis of the period between 2007 and 2017, the growth of relatively low-carbon natural gas-fired generation, increase in wind and solar generation, and energy efficiency were responsible for 34%, 25% and 25% of emission reductions respectively. (Goff, 2017) [1]

The emission reductions associated with gas generation displacing coal generation were made possible by the commercialization of natural gas "fracking" technologies including 1) advanced drilling technologies and computational power to more efficiently control the direction of underground drilling, and 2) the use of water, sand, and chemicals to hydraulicly fracture deep geologic formations to release natural gas. The emergence of these technologies in the 2000s coincided with roughly a 50 percent decline in natural gas prices between 2008 and 2012 and further declines since then. (U.S. Energy Information Administration, 2021a) These price reductions materially reduced the cost of natural gas relative to coal, allowing for gas generation to displace coal generation and reduce emissions in the electric sector.[2]

Substantial declines in the costs of wind and solar photovoltaic (PV) generation technologies have helped spur increasingly rapid deployment of these technologies, displacing fossil generation and further reducing sector carbon emissions. The U.S. average levelized cost of onshore wind projects declined by over 60 percent, from $90/MWh in 2010 to $33/MWh in 2020. (Wiser, et al., 2021) The cost of utility-scale solar PV projects declined even more. The U.S. average levelized cost of this type of generation declined from $220/MWh in 2010 to $34/MWh in 2020, a cost reduction of 85%. (Bolinger, Seel, Warner, & Robson, 2021)

Importantly, the technical advances and cost reductions that have enabled these drivers of emission reductions are the result of a mix of private sector investments and government policy both in the U.S. and overseas. In the U.S., at the state and regional levels, supportive policies have included a large and growing number of RPS and Clean Energy Standard (CES) programs requiring electric companies to procure a minimum amount of renewable or clean energy each year, typically increasing over time. They also include two major greenhouse gas emission cap-and-trade programs, one in California and the other across the RGGI region. While several widely recognized proposals to establish federal carbon emission regulations have not been approved (including for example the Waxman-Markey Bill of 2009 and more recently the Obama administration's Clean Power Plan), the federal government has successfully advanced the development and commercialization of a wide range of low-carbon technologies through fundamental research at the Department of Energy's national laboratories and the Advanced Research

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[1] Discussions of carbon emissions in this chapter generally refer to the emissions directly resulting from power plant operations, not the larger technology "lifecycle" emissions that also include fuel production, fuel transportation, power plant manufacturing and material disposal.

[2] The increase in U.S. natural gas spot prices during 2021 has been forecasted by the U.S. EIA to moderate in the coming years and is not expected to materially reverse this long-term trend.

Projects Agency – Energy (ARPA-E) program,[3] and through accelerated tax depreciation and tax incentive policies.

These technological and policy developments have led to major changes in the U.S. generation mix and the emission reductions previously cited. Since 2011, non-hydropower renewables have grown from less than 5 percent of U.S. generation to almost 15 percent of U.S. generation, natural gas-fired generation has grown from less than 25 percent to roughly 35 percent (now the largest single source), and coal-fired generation has declined from around 45 percent to less than 25 percent. (U.S. Energy Information Administration, 2021b) In recent years, wind and solar have represented more than half of total U.S. electric generating capacity additions. (Bolinger, Seel, Warner, & Robson, 2021)

As detailed in the previous chapter, these national trends look somewhat different when examined on a regional level. Regional variations are driven by differing natural endowments of coal, natural gas, hydro, solar and wind resources, and differing state priorities for energy and environmental policies. Electric generation fueled by natural gas has increased the most in regions such as the Northeast and the Southeast, which have ready access to low-cost supplies from producing regions including from the states of Pennsylvania and Texas. The growth of wind generation has been the greatest in the Great Plains, Rockies, Midwest and Gulf Coast states. The growth of solar has been the greatest in the Southwest, West Coast, Hawaii and Southeast. The largest declines in coal generation have occurred in the Midwest and Northeast where relatively high-cost coal has been competitively disadvantaged relative to lower cost natural gas. These changes reflect the patchwork quilt of regional market and policy conditions in the electric sector across the country discussed in the previous chapter.

Looking at recent federal policy, the Biden administration has set an ambitious climate and clean energy policy agenda during its first year. As of this writing in late 2021, the United States has rejoined the Paris Agreement and established several greenhouse gas emission goals: to reduce economy-wide emissions in 2030 by 50 percent or more relative to 2005 levels, to eliminate electric sector carbon emissions no later than 2035, and to reach net-zero economy-wide greenhouse gas emissions no later than 2050. The administration also launched a "whole-of-government" approach to achieve these goals. This involves a mix of legislation, such as the bipartisan Infrastructure Investment and Jobs Act (IIJA) which passed Congress and was signed into law in 2021. It also involves executive and regulatory actions including, for example, a directive for federal agencies to procure clean electricity and the revival of the Department of Energy's loan program office for innovative energy projects. (The White House, 2021a) (The White House, 2021b) The IIJA legislation, among other provisions, established new policies to support the development of zero-carbon fuels and carbon capture technologies, reduce methane emissions, maintain the country's nuclear fleet and invest in new electric transmission. (CATF, 2021) More ambitious climate legislation is pending as of this writing and further executive and regulatory action is expected.

Growth Opportunities for the Electric Industry

As mentioned, fully or nearly decarbonizing the U.S. electric sector will require replacing essentially all of today's coal and natural gas-fired electric generation or at least eliminating the carbon emissions from that generation. This will be a large lift. As of 2020 fossil generation in the electric power sector still represented 58 percent of the nation's electric energy and 64 percent of its generating capacity. (U.S.

[3] ARPA-E is an agency in the United States Department of Energy tasked with promoting and funding research and development of advanced energy technologies.

Energy Information Administration, 2021c) In addition, decarbonizing other sectors of the nation's economy, including transportation, industry and buildings, is widely expected to be accomplished by electrifying many energy services in those sectors with zero-carbon or low-carbon electricity. This process, sometimes referred to as "beneficial electrification," would substantially expand the demand for electricity. New electric loads would come from charging electric vehicles, powering electric industrial boilers (often for process heat), using electrolysis to produce hydrogen (a zero-carbon fuel used in a variety of industrial applications), installing residential and commercial water heaters, installing heat pumps for space heating, and deploying direct air capture systems (a process for capturing carbon dioxide from ambient air for sequestration underground or for use in manufacturing processes).

To illustrate, one scenario for expanding electric service over time in the home heating and transportation sectors, drawn from a recent nationwide study, would involve the following. Residential space heating would transition from two-thirds fossil fuel today (predominantly oil and natural gas) to almost entirely electric heat pumps (80 percent) and electric resistance heating (20 percent) by 2050. Residential water heating would transition from roughly one-half fossil fuel today to a mix of electric heat pumps (60 percent) and electric resistance heating (40 percent) by 2050. In the transportation sector, cars and light-duty trucks would transition to almost all electric vehicles by mid-century. Medium and heavy-duty trucks would transition to a mix of technologies, with about 80 percent being powered by either electricity or hydrogen fuel cells. (Sustainable Development Solutions Network, 2020)

Looking at the aggregate impact of these changes on the electric sector, a review of studies conducted between 2015 and 2021 reveals total U.S. electric generation would need to more than double (a 137 percent increase) relative to today's levels by 2050.[4] At the same time U.S. electric capacity would need to roughly triple (a 278 percent increase).[5] These increases would be needed even after accounting for ambitious improvements in the efficiency with which energy is used by consumers, and opportunities to charge batteries and electric vehicles during nighttime periods of low electric demand.

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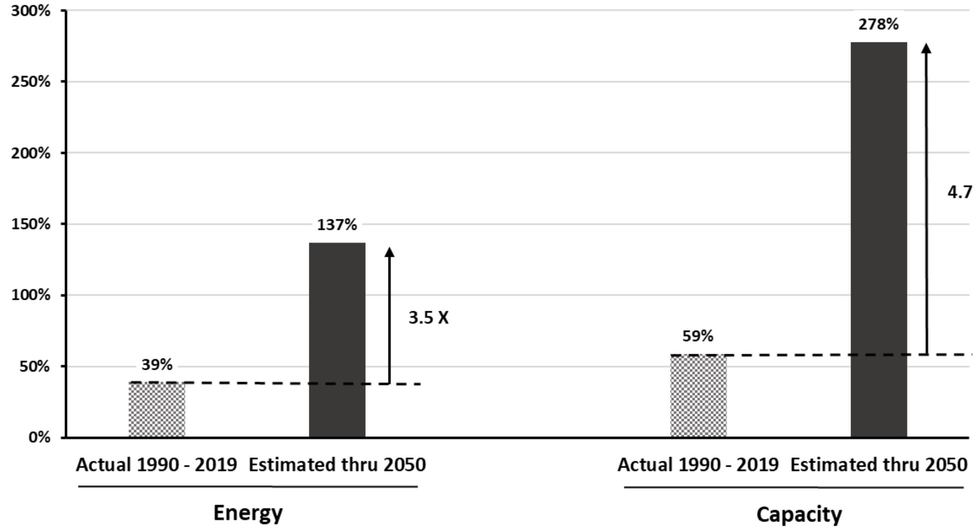
4 Electric generation is also referred to as electric energy.

5 Electric capacity is a measure of the maximum amount of energy that may be generated at a point in time. Generating technologies with relatively low utilization rates or capacity factors, like solar and wind plants, require relatively large amounts of capacity to produce the same amount of cumulative electric generation as other technologies with higher capacity factors. Because of this, the proportional increase in capacity required to achieve deep decarbonization is typically larger than the proportional increase in generation.

Figure 6.1

Estimated Increase in the Electric Sector Growth Compared to History



Source: Based on data presented in The NorthBridge Group, 2021. *Review and Assessment of Literature on Deep Decarbonization in the United States: Importance of System Scale and Technological Diversity.*

This increase suggests a rate of expansion for the U.S. electric sector far beyond that experienced over the last 30 years: about 3.5 times recent history on an energy basis and over four times that on a capacity basis.[6]

Not surprisingly, this unprecedented expansion would drive large investment opportunities across a wide range of electric generation, energy storage and transmission technologies. The dollar value of the investments required is magnified by the fact that many low- and zero-carbon generating technologies are more capital intensive than the technologies they will replace. One recent study estimated that the U.S. would need to make cumulative capital investments in generation and related infrastructure of close to $2.6 trillion by 2030 and $10 trillion by 2050. (Larson, et al., 2020) These correspond to average annual capital investments over the 30-year period of about $300 billion to $350 billion. To put this in context, U.S. investor-owned electric utility capital expenditures in 2019 were $125 billion. (Edison Electric Institute, 2020) Consequently capital investments would need to increase several-fold over the 30-year period.

Several recent studies of deep decarbonization pathways in the U.S. point to a common set of technologies and investment priorities for the years leading up to 2030 and then diverge over the following decades as technical, economic and market uncertainties have a larger impact on modelling results and possible futures. The common investment priorities for the decade of the 2020s mostly include building out renewable generation (solar PV, onshore wind, and offshore wind), maintaining existing low- and zero-carbon capacity (including nuclear and natural gas plants), expanding transmission

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[6] Based on analysis by the NorthBridge Group of modeling studies examining economy-wide deep decarbonization pathways in the U.S. The estimated increase in energy is the average of cases from nine national studies reporting total energy requirements. The estimated increase in capacity is the average of cases from six studies reporting total capacity requirements. (The NorthBridge Group, 2021)

infrastructure to facilitate inter-regional transfers of power and improve the resiliency of the existing electric grid system.

The largest of these investment priorities have been estimated to include the following items: (Larson, et al., 2020) (Williams, et al., 2021)

- Building 500 GW to 600 GW of new onshore and offshore wind and solar PV capacity (which is roughly three times the currently installed U.S. wind and solar capacity and 50 percent of total U.S. installed electric capacity of all fuel types as of the end of 2020).
- Building almost 200,000 GW-km of new transmission (roughly a 60 percent increase over current transmission capacity) to connect new renewable generation supplies with load centers and improve the resiliency of the electric grid.
- Building 5 GW to 15 GW of new battery storage, which is five to 15 times the battery storage currently installed in the U.S.
- Investing to maintain existing nuclear power plants (that are determined to be safe to operate) to provide dependable, around-the-clock zero-carbon generation and existing natural gas-fired generating capacity to maintain system reliability.
- Capturing and sequestering carbon emissions from five to ten natural gas-fired power plants and carbon-emitting industrial facilities; and constructing an interstate pipeline system (roughly 20,000 km in scale) to transport captured carbon dioxide from point of capture to major storage basins.
- Building end-use energy infrastructure to electrify light-duty vehicles (estimated at 50 percent of new vehicles sold), and heat pumps for space heating (estimated at 25 percent of residences).

Uncertainties in the Energy Transition

While holding out the prospect of enormous investment opportunities for businesses, a U.S. energy transition that achieves net-zero economy-wide greenhouse gas emissions by midcentury is a daunting challenge as it rests on a rapid and fundamental restructuring of the country's entire energy sector, a collection of large, diverse and complex industries. It should not be surprising then that the transition is uncertain, both in its timing and its eventual technological direction.

There are at least three main sources of uncertainty. These stem from challenges related to: 1) establishing ambitious and sustainable government policies consistent with midcentury net-zero emission goals, 2) rapidly scaling deployment of electric infrastructure and consumer acceptance of new technologies to electrify other sectors of the economy such as transportation and home energy services, and 3) anticipating the mix of variable renewable (wind and solar) technologies and firm clean energy technologies needed for the electric sector to be fully decarbonized in a reliable, affordable, socially acceptable and timely manner.

Each of these challenges will influence what the transition means for U.S. businesses.

Ambitious and Sustainable Policies

The progress made to date in improving the performance, reducing the cost and advancing deployment of low-carbon and zero-carbon generating resources is in part due to federal and state policies. Supportive government policies will continue to be needed going forward to rapidly deploy proven technologies and commercialize new advanced technologies. One question is whether these government policies will be sufficiently ambitious and stable over time to achieve net-zero economy wide emissions by midcentury, and this will of course depend on the degree of public support for these policies.

At the federal level, technology innovation policies including fundamental research performed at the Department of Energy's national laboratories and ARPA-E, along with many decades of collaboration among government, universities, research institutions, industry, and entrepreneurs, have made the U.S. the global leader in the development of new electric technologies. (Breakthrough Energy, IHS Market, Energy Futures Initiative, 2019) (National Academies of Sciences, Engineering, and Medicine, 2021) These programs and other federal policies including tax incentives for solar, wind and carbon sequestration that help "push" new emerging technologies into the commercial marketplace have often had bipartisan political support. However, policies to "pull" new technologies into the marketplace, such as carbon taxes, cap-and-trade programs, and greenhouse gas emission limits, have not had sufficient support at the federal level to be established. The existence, stringency, design and predictability of such push and pull policies will heavily influence the pace and character of the transition but are subject to considerable uncertainty.

Policy analysts generally agree the most economically efficient policy approach to reduce carbon emissions would involve a nationally uniform carbon price, which could take the form either of a tax on carbon emissions or market-based emission credit price such as in a cap-and-trade program. Either type of policy could be designed to achieve a desired level of decarbonization over time in a predictable manner and achieve related policy goals. (Phillips & Reilly, 2019) But despite several efforts stretching back over 20 years, federal policymakers have yet to develop sufficiently broad agreement to pass these types of policies into law. This period includes proposals put forward by Republican presidential candidates in the 2000s, the American Clean Energy and Security Act of 2009 (also known as the Waxman-Markey bill) and President Obama's Clean Power Plan in 2015.

In recent years, a wide range of policy proposals have been advanced at the federal level that rely heavily on sector-specific policies and elements of industrial policy. Examples include the Green New Deal, which was put forward to address climate change through industrial policies linked to non-environmental policy goals, and sectoral policies such as a clean energy standard (a market-based system requiring a certain percentage of electric sales come from zero- and low-carbon generating technologies), expanded clean energy investment and production tax incentives, reform of the centralized regional wholesale electric markets to support clean energy deployment, vehicle emission standards, government procurement guidelines to increase the amount of low-carbon electricity purchased by federal agencies, and use of federal power marketing administrations or other government entities to more directly support development of clean energy and electric transmission.

As mentioned earlier, the Biden administration established an ambitious agenda for clean energy and climate policy. In its first year, the administration pursued that agenda in part by initiating several executive and regulatory actions including directing federal agencies to procure carbon free electricity and reviving the Department of Energy's loan program for innovative clean energy projects. It also secured passage of the bipartisan Infrastructure Investment of Jobs Act which includes support for clean energy technologies as listed earlier in this chapter. Another administration initiative, the Build Back Better Act, has provisions to develop and deploy clean energy including extended and reformed tax incentives for renewables, carbon capture, hydrogen, advanced nuclear, existing nuclear, and high-voltage transmission. That Act was passed by the House as H.R. 5376, but as of this writing in late 2021, appears unlikely to be passed by the Senate. If the Build Back Better Act does not go forward in some form, other executive and regulatory actions will be needed to achieve all the administration's climate goals.

Going forward, regardless of the precise mix of federal clean energy and climate policies, the states are widely expected to continue to play a prominent role in the energy transition. This could involve increasing the stringency or accelerating the timelines of state clean energy standard programs, expanding the scope of carbon pricing programs (such as RGGI and California's cap and trade program), expanding the use of targeted procurement programs for clean energy resources such as offshore wind, and adopting analogous programs for the transportation sector. Programs such as these will evolve and likely expand over time on an incremental basis as they have done in recent years. A key point of uncertainty is whether these types of programs will be largely restricted to states with relatively low greenhouse gas emissions or instead be adopted more broadly by other states including those with higher emissions.

Importantly, both federal and state policies will only be sustainable over the coming decades if they are compatible with the provision of energy services to consumers and businesses that are reliable, affordable to all customers, and aligned with other societal priorities including employment and social equity, for example supporting the "just transition" of local communities that are today largely dependent on fossil fuel production and consumption. Federal policies will also need to be sufficiently flexible to conform with the differing resource endowments, public priorities, and electric regulatory systems in major regions of the country.

If state and federal policies are not adequately aligned in these ways, public pressure will inevitably mount to delay, revise or reverse some policies. At the state level, the announcements in 2021 that Massachusetts will not participate in the regional Transportation and Climate Initiative and that Virginia will withdraw from RGGI illustrate the uncertain nature of policy support for some climate initiatives.

Similarly, the clean energy and emission goals established by electric utilities, large energy-consuming corporations, and financial institutions will only be sustainable over time and achievable if they can be achieved while also meeting other customer, investor, and societal goals.

Scaling Deployment and Consumer Acceptance

With a doubling or tripling in the size of the electric sector and need for perhaps $10 trillion of capital investment over three decades, another source of uncertainty is whether the industrial and consumer changes needed to achieve this transformation can be practically scaled in a timely way.

There are several elements to this, most importantly: siting and permitting electric infrastructure, expanding industrial supply chains, and gaining widespread consumer acceptance.

The first of these involves the ability to site, permit and gain local community support for new clean energy generating plants and infrastructure at a pace several times higher than experienced in the last three decades. This becomes particularly daunting when accounting for the land use and community impacts of wind, solar and transmission projects which are widely expected to comprise a large majority of new energy infrastructure. According to one recent study, by midcentury onshore wind and solar could span almost 600,000 sq-km of land area, roughly the size of Illinois, Indiana, Ohio, Kentucky, Tennessee, Massachusetts, Connecticut, and Rhode Island combined. (Larson, et al., 2020) At the same time, the nation's transmission system may need to be doubled or tripled. (The NorthBridge Group, 2021) The land use issue is particularly important for pathways that rely heavily on variable renewable technologies because these technologies are less energy dense than some other generating technologies and rely on long distance transmission to connect resource rich regions with load centers. Policy and corporate business practice reforms to better engage local communities and share the economic benefits of clean energy development could help address these issues, but are only now beginning to be explored in the U.S.

The most likely alternative technology pathways to extensive wind and solar development would involve greater deployment of more energy dense generating technologies such as fossil plants with carbon capture and advanced nuclear technologies. However, these are technologies that have limited social license in many regions of the country today. These two factors, the extensive land and community impacts of variable renewables and the social opposition to carbon capture and nuclear technologies, may make rapid scaling of clean energy infrastructure a difficult and uncertain enterprise.

Another challenge involves rapidly scaling supply chains for electric energy-related industrial and consumer goods. These include raw material procurement, manufacturing and transportation of electric plant and equipment, workforce training and construction services. As in recent years with the imports of solar panels from China and offshore wind technology from Europe, the scaling of supply chains in future years will depend to some extent on international trade policies and the extent to which manufacturing is located overseas or in the U.S. The ability to rapidly scale these systems will influence the opportunity of the U.S. to capitalize on its world-class ability to develop advanced energy technologies and use the energy transition to grow the nation's export markets.

The third challenge revolves around the changes in consumer home energy systems, widespread market penetration of electric vehicles, conversion of industrial fossil boiler systems to electricity and use of zero-carbon fuels in industrial manufacturing processes. The most recent economy-wide analyses of deep decarbonization pathways often assume consumers and industry will be willing to rapidly adopt these new technologies and systems and accept that some of this new electric demand will be curtailable or interruptible when inadequate electricity supply is available to serve those electric demands. In essence, by the time full economy-wide decarbonization is achieved, these analyses often assume the technical operations of the electric grid will be largely reversed relative to how it has been operated historically: instead of managing firm, generating resources (power plants physically capable of producing energy on a reliable and regular basis throughout the year) to satisfy firm "on-demand" electric loads as is currently done, large amounts of flexible consumer and industrial electric load will be managed within the available limits of variable electric supplies sourced predominantly from variable wind and solar moderated with battery storage.[7] For some industrial processes that might otherwise operate on a regular, around-the-clock basis throughout the year, this implies operating in a new manner, with plant utilization at any point in time possibly limited by the availability of electricity. This in turn could influence the daily and seasonal time patterns of workforce requirements at these facilities. For the public, this new approach to operating the electric system, with flexible loads managed within the limits of variable supplies and battery systems, suggests consumers will need to be comfortable with their electric vehicle charging and home appliance use being subject to the availability of electric supplies, at least during some hours of the year.

These industrial and consumer scaling challenges may well be overcome in one form or another through time. But the magnitude and speed of the anticipated changes add uncertainty to the pace of the energy transition, and the potential for consumer dissatisfaction creates risk for policy reversals.

These challenges could also influence the mix of clean energy resources eventually developed. For instance, local community resistance to the siting of onshore wind or solar PV, or marine community opposition to offshore wind, could slow or limit the deployment of those technologies and shift the mix of new generation required to meet climate goals to other types of clean energy that might be more readily sited and permitted. And consumer or industrial reluctance to have some of their electric usage curtailed

[7] Some amount of firm clean electric generation would also be available to serve other types of electric demand that is unwilling or unable to be managed in a more flexible way.

or remotely managed would increase the need for clean energy technologies that are reliably firm rather than variable.

Alternative Technology Pathways

Recent studies, as described before, point to the need for many common types of investments through 2030. These include, in particular, wind, solar and transmission. However, the mix of new electric investments needed after 2030 is less certain. The same studies that point to a common set of investments over the next decade also point to several differing long-term technological pathways for the electric sector starting in the 2030s and beyond. These technology pathways generally fall into two groups, variable renewable-dominant systems and systems with a more diversified mix of technologies.

Variable renewable-dominant systems can be thought of as electric systems where wind and solar supply roughly 85 percent or more of total electric energy and are complemented by much smaller quantities of firm resources such as existing hydro, existing nuclear, and natural gas-fired electric energy (fueled either by natural gas without carbon capture controls or by zero-carbon liquid fuels of various types). In contrast, more diversified electric systems are comprised of variable renewables complemented with larger quantities of existing hydropower and nuclear along with new firm clean energy technologies to help maintain system reliability and provide zero-carbon energy. Examples of new firm clean energy technologies include natural gas-fired electric generation with carbon capture and sequestration, fossil-fired oxy-combustion technologies with carbon sequestration, advanced nuclear electric generation including small modular “shipyard-manufactured” fission reactors or fusion reactors, hydropower, geothermal power, and zero-carbon liquid fuel-fired electric generation such as hydrogen.[8]

While wind and solar generation have become cost-competitive sources of energy in many regions, deep decarbonization studies have shown that a diverse mix of clean energy technologies, including both variable renewables and firm electric generating technologies, will be needed to achieve full decarbonization. Firm electric technologies are important for several reasons. They help maintain reliable electric service for customers requiring on-demand electricity by generating electricity when supplies from wind and solar are insufficient. (Lott & Phillips, December 2021) They reduce the overall system-wide cost of electric service at high levels of decarbonization when the incremental cost of adding additional variable renewables (along with complementary transmission and batteries) rises to the point where they exceed the incremental cost of adding firm clean energy generation). By expanding the tool kit of clean energy options, they provide flexibility to achieve ambitious decarbonization goals if the siting, permitting, scaling and consumer acceptance challenges discussed earlier slow the pace of rapidly deploying variable renewable resources. And finally, CCS technologies are expected to be particularly valuable in helping decarbonize some industrial processes that currently use natural gas as a feedstock.

The eventual pathway that emerges in the U.S. is uncertain because of the many technological, economic, and social unknowns at play. Continued cost reductions and performance improvements in onshore wind, offshore wind, solar PV, and battery technologies are widely expected by industry and technology experts. Advanced natural gas-fired oxy-combustion technologies with carbon sequestration are also now being demonstrated commercially in the U.S. Downscaling of nuclear fission technologies coupled with modular shipyard construction could make forms of that technology cost competitive in some markets, perhaps as “drop in” replacements for coal-fired boilers in some of today’s coal power plants. This would have the benefit of helping to sustain local communities in coal-heavy regions of the country. Other

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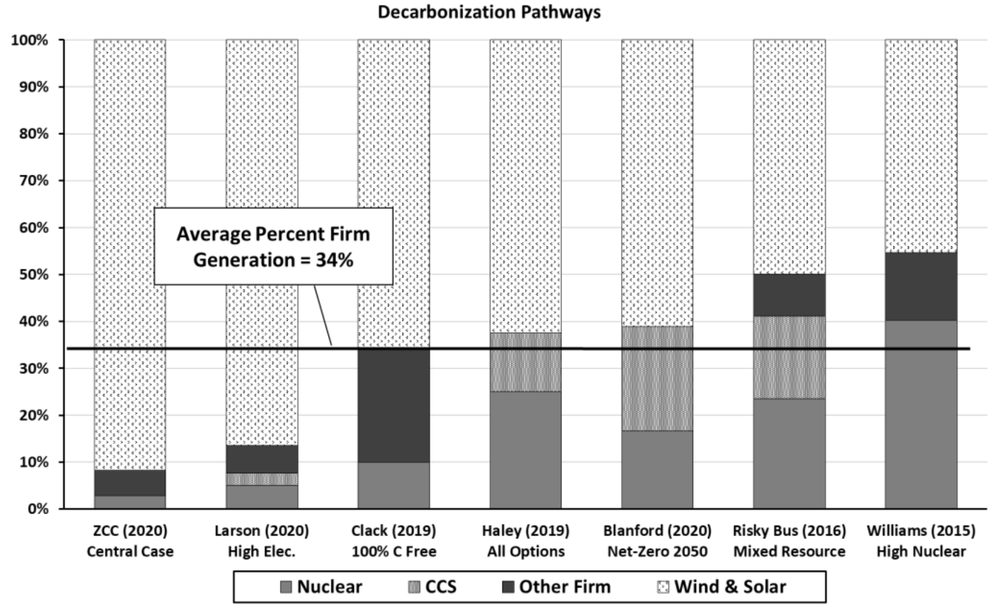
8 Hydrogen may be produced from natural gas through steam reformation with carbon capture or electrolysis with electricity supplied from zero-carbon generation.

advanced technologies such as long-duration energy storage or "deep hot rock" geothermal could be demonstrated and become commercially competitive. The degree of success of any of these technical and economic developments is uncertain. The uncertainty is compounded by the social dimensions of siting and permitting new energy infrastructure, and how these differ across alternative generating technologies and regions of the country. Difficulty siting new infrastructure at scale could focus development efforts on repurposing existing coal and gas power plant sites with advanced low carbon generating technologies, and relying on existing transmission, rail, and pipeline corridors to expand electric transmission capacity.

The eventual decarbonization pathway in the U.S. will also likely vary from region to region of the country depending on the relative strength or weakness of the area's wind and solar endowments, ability to build new long-distance transmission, the availability of other natural resources (such as hydro, biomass, and access to geologic sequestration), and existing energy infrastructure (including nuclear, hydropower, and pipelines for fuel transportation).

These many considerations lead to a range of estimates for the mix of electric generation that may eventually be seen in a fully decarbonized electric sector. The following figure illustrates this point by summarizing the mix of U.S. electric generation estimated in seven national, deep decarbonization studies. The average generation mix across the studies corresponds to 65 percent variable renewables (such as wind and solar) and 35 percent firm generation (such as nuclear, fossil with carbon capture and storage (CCS) and firm renewables like hydropower). Some of the most recent studies estimate energy shares for wind and solar of 85 percent or more, reflecting the increased cost competitiveness of wind and solar technologies. But collectively, the studies point to a wide range of outcomes, with the potential for somewhat smaller shares for wind and solar resources (down to around roughly 50 percent) and correspondingly larger shares for firm clean energy technologies. The range of these modelling results illustrates the potential for alternative pathways to develop over time. (The NorthBridge Group, 2021)

Figure 6.2
2050 Generation Mix in Low-Cost Scenarios from National Studies Examining Multiple Decarbonization Pathways



Source: Adapted from The NorthBridge Group, 2021. *Review and Assessment of Literature on Deep Decarbonization in the United States: Importance of System and Technological Diversity.*

Implications for Electric Businesses and Decision Making

The fundamental challenge for businesses and investors in the electric sector is how to capture the enormous opportunities for growth while at the same time managing the complex localized commercial risks that arise out of the policy, scaling, and technology uncertainties just discussed. Policy uncertainty, at both the federal and state levels, dampens the financial incentives of the private sector to invest in low-carbon technologies at the massive scale required to meet ambitious emission goals. Policy uncertainty also preserves the opportunities that the owners of today's carbon-emitting fossil power plants have to continue to operate and earn financial returns, at least for the time being. The scaling uncertainties with permitting infrastructure, supply chains, and consumer acceptance raise the cost and financial risks of rapid business expansion and building market share. And the uncertainty around technology pathways makes it more difficult for early investors to demonstrate new technologies and build the first-of-a-kind facilities needed to improve performance, reduce costs and commercialize those technologies. It also raises the risk to investors that, absent long term fixed-price contracts that pass market risk to other parties, capital investments will turn out to have lower than anticipated rates of return. All these uncertainties are made more complicated by the patchwork quilt of market and regulatory conditions currently in place across the country.

To address these challenges, businesses in the electric sector will need to consider three questions: 1) How to rapidly deploy technologies that have already been largely commercialized, 2) How to demonstrate and commercialize new advanced clean energy technologies, 3) How to manage the existing fleets of fossil and nuclear generating plants. Each of these is addressed in the following sections.

Deploying Commercial Technologies at Scale

Over the next ten years, through at least 2030, most decarbonization in the electric sector is anticipated to come from deploying zero-carbon generating technologies that have already been at least partially commercialized in parts of the country – solar PV, onshore wind and offshore wind – along with complementary electric infrastructure such as transmission, batteries and distributed energy resources. As mentioned earlier, to achieve net-zero U.S. economy-wide emissions by 2050, the amount of wind and solar capacity alone that would need to be deployed by 2030 could approximate roughly half of today's total U.S. electric capacity. This level of deployment corresponds to an average of 50 GW to 60 GW annually, which is close to three times the wind and solar installed annually between 2015 and 2020. Further, the nation's transmission system would need to expand by more than 50 percent.

Achieving this ambitious level of deployment during the 2020s will hinge on addressing the policy and scaling issues discussed before, most importantly new federal or state "pull" policies, interstate transmission development and reforms to facilitate the siting and permitting of new facilities.

Wind and Solar

If solar and wind capacity is to expand by the magnitude estimated in recent studies, it would represent the single largest growth opportunity associated with the energy transition in the U.S. over the next decade. But for businesses involved in wind and solar development, rapidly scaling deployment raises siting and permitting, contracting, procurement, financing and transmission access questions, especially in regions of the country with competitive wholesale power markets.

Non-utility developers of solar and wind looking for rapid expansion of their portfolios may need to consider the mix of long-term, fixed-priced power purchase agreements (PPAs) and merchant projects (which place greater risk of cost recovery on investors rather than utility ratepayers.) For many years, the comparatively large up-front capital costs of wind and solar facilities (relative to total project costs), wholesale market price uncertainty and lack of ambitious carbon pricing or clean energy standards in many regional markets have led most developers to seek long-term, fixed-priced contracts from utilities or corporate buyers. This practice allocates financial risk to ratepayers and buyers, reduces investor risk exposure, and allows developers to finance projects with a lower cost of capital. This is the commercial standard today in the U.S.

Continued technology advances that allow zero-carbon investments to be commercially competitive with other sources of wholesale electricity without policy supports (such as a CES, carbon taxes or tax incentives) would allow clean energy developers to invest on a merchant basis without long-term, fixed-priced PPAs. This merchant approach to financing investments, which is the commercial norm in most non-electric sectors of free-enterprise economies, would be most practical for relatively large well-capitalized companies in a position to accept greater financial risks. Eliminating the need to secure new PPAs for each project could simplify the contracting and financing process for investors and speed the deployment of clean energy technologies. But in the absence of such technological advances or new ambitious and sustainable energy policies, continued reliance on long-term fixed-priced PPAs is likely to be the default commercial pathway in most parts of the U.S.

For renewable energy developers in regions of the country with strong wind and solar technical potential looking to sell output in other regions of the country with demands for clean energy, another commercial question is whether and how to bundle wind or solar projects with new interstate transmission. The economics of these PPAs will be affected by the technical structure of wholesale electric markets (e.g., whether they are bilateral, energy-only, or energy and capacity markets), the design of renewable energy and clean energy credit products, and the way these systems evolve in future years.

For vertically integrated utilities with their own generating assets, another question is whether and how much wind and solar capacity might be owned as opposed to contracted from independent developers. These decisions will be influenced by several considerations including the utility's relative capability in project development, tax law considerations and competitive procurement policies established by their state regulators.

And finally, as wind and solar technologies achieve high levels of market penetration and displace other sources of electric generation with higher variable operating costs, the wholesale price of electric energy during hours of high wind and solar production will decline. During hours when wind and solar displace all other sources of electric generation, wholesale prices will likely drop to zero, eliminating the economic incentive for continued production. This concern has led policy analysts to explore ways that price formation practices in centralized wholesale power markets might be reformed to provide better economic incentives to deploy and operate clean generating technologies in deeply decarbonized power markets.

Transmission

The 50 percent expansion of the nation's transmission system over the next 10 years, and the doubling or tripling estimated in some studies by midcentury, point to very large investment opportunities for transmission developers. But new long-distance transmission facilities have in the past been notoriously difficult and slow to develop, often taking well more than a decade for successful projects (and resulting in failure for others).[9] There are several reasons for this, including: the diffused nature of the reliability and economic benefits which makes it difficult to assign cost responsibility to ratepayers and users of the system; local community, incumbent generator and environmental opposition to project development; a lack of centralized regional and national transmission planning; and the multiple layers of local, state and federal regulatory approval required for inter-state projects.

Some of these hurdles could be overcome by co-locating new capacity with existing transmission lines and other infrastructure rights-of-way (railroad, highways, pipelines etc.), reforming federal and state regulations to speed and reduce the uncertainty associated with project review, adopting "best practice" project development processes to more effectively engage, compensate and build support from local communities, and expanding the use of independent merchant project business models (as opposed to traditional utility projects with socialized cost recovery from ratepayers).[10]

The outcome of efforts to speed the deployment of interstate transmission will likely have an impact on the mix of variable renewable and firm clean energy that emerges over time. For instance, long-distance transmission lines from the Great Plains states and Southwest to population centers in other regions could facilitate development of wind and solar in those supply regions, while their absence would require more new clean energy generation sited closer to load centers and perhaps shift the generation mix towards other technologies.

Batteries

The 80 percent decline in the cost of lithium-ion battery technology that occurred in the years leading up to 2020, deployment of wind and solar generation, appreciation of the technical services that batteries can provide to the electric grid, and policy support from some state regulators all point to an expectation of robust battery investment growth going forward. The federal government recently estimated that a total of over 12 GWs of large-scale battery storage capacity would be installed by the end of 2023, more than a ten-fold increase since 2019. (U.S. Energy Information Administration, 2021d)

At the same time, the relatively short duration of today's batteries' storage capability, generally four to six hours, makes them expensive options to overcome the seasonal variability of solar and wind generation, and may limit their longer-term market penetration. In the long term, success is likely to hinge in part on business model and regulatory reforms including the adoption of long-term, fixed-priced contracts and regulated cost recovery that allow for capital costs to be financeable and commercially viable in diverse market regimes.

Distributed Energy Resources

Distributed energy resources include a varied mix of generating, storage and other technologies such as rooftop solar, batteries, backup conventional electric generation (including internal combustion engines), advanced metering, and demand management electronic controls. All these are located on the utility's distribution system (and not on the transmission system) or directly on a customer's premises. In many cases, the distributed energy resource is configured to be "behind the meter," meaning that the resource's output is treated (from the standpoint of utility planning and operations) as a reduction in the customer's metered load and grid-level electric demand. While not all distributed energy resources are low- or zero-

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[9] See *Superpower: One Man's Quest for Transform American Energy* by Russell Gold (2019) for a history of the Clean Line Energy proposals to develop and transfer large scale wind energy from the Great Plains to the east.

[10] New York's Accelerated Renewable Energy Growth and Community Benefit Act is one example of efforts to expedite the siting and permitting of clean energy infrastructure.

carbon technologies, some, such as rooftop solar, do not directly emit greenhouse gases when they produce electricity. Utilities can deploy distributed energy resources in specific locations as a solution to manage localized system congestion. Customers can deploy distributed energy resources to actively manage their electricity usage and improve the reliability of their electric service. When the costs of distributed resources are less than the portion of utility rates that are avoided by them, customers can reduce their electricity bills through adoption of distributed energy resources. The value of demand management services and improved reliability to customers is important in evaluating the economics of distributed energy resources because the cost of many distributed energy resources are higher than the cost of corresponding central station generating technologies which often benefit from greater economies of scale. (Lazard, 2020) For these resources to be widely adopted by utility customers, these benefits will need to outweigh the cost premium. While generally considered to be a smaller part of the overall industry-wide energy transition, distributed energy resources represent a promising business opportunity for many utilities, equipment suppliers and project developers, particularly if regulatory reforms seeking to facilitate their adoption are successful.[11]

Commercializing Advanced Technologies

Looking ahead over the next several decades, the second type of business challenge is how to commercialize advanced technologies that are likely to be valuable and perhaps essential to achieve net-zero emission goals on an economy-wide basis but are not yet demonstrated or widely available on a commercial basis. These include advanced technologies to provide clean firm capacity and energy (such as next-generation small modular reactors, generation IV fission reactors, fusion reactors, advanced low-carbon fossil-fueled oxy-combustion and deep hot rock geothermal technologies), store electricity over extended periods of time (such as thermal energy storage), capture carbon dioxide from fossil fuel-fired electric generation plants and industrial processes and produce hydrogen through electrolysis. Capturing carbon dioxide and producing hydrogen through electrolysis or steam methane reformation processes on a widespread basis will also require extensive interregional transport, storage and sequestration networks.

While some deep decarbonization analyses suggest these technologies may not need to be widely deployed until the 2030s or later, developing and commercializing them before then is important because of the long periods of time required to fully demonstrate, commercialize and deploy new technologies, the need for supporting infrastructure such as pipeline and storage networks and, if widespread deployment of renewables and transmission is delayed, the need for other advanced technologies to be deployed more quickly.

The commercialization challenge for businesses looking to advance these technologies is to demonstrate them at pilot and commercial scales, improve their performance and drive down costs to commercially competitive levels, develop supply chains, establish workable business models, and gain consumer acceptance. Successful technologies will need to exceed competitive benchmarks based not only on today's technologies but also tomorrow's advanced technologies with lower costs and improved performance. They will also need to be designed to operate and compete in an integrated electric systems and competitive wholesale markets; this is likely to put a premium on the ability to complement the variability of wind and solar resources by dispatching them when wind and solar are not generating

[11] For example, FERC Order 2222, issued in September 2020, was intended to remove barriers preventing distributed energy resources from competing on a level playing field in the organized capacity, energy, and ancillary services markets run by regional grid operators.

output. The federal ecosystem of fundamental research, technology advancement and project demonstration can be of great value in this process.

The commercialization of advanced technologies is an area of great activity in the electric sector. Many important technological advances have occurred in recent decades including the commercialization of natural gas-fired combined cycle technology, onshore and offshore wind turbines, solar PV panels, and lithium-ion batteries. There is much ongoing public and private sector activity including work at the DOE national laboratories, the federal ARPA-E program, early project developments supported by federal tax incentives to sequester carbon dioxide captured from electric generating and industrial emission streams,[12] and early commercialization of advanced oxy-combustion generating technologies. Further, more than a dozen companies are working on advanced nuclear technologies, some of which are in the stages of licensing next-generation technologies. (Nuclear Innovation Alliance, 2021)

But the energy sector, with its long technology development cycles and high capital requirements, also presents particularly difficult innovation challenges. Over the years, many high-profile development efforts have not come to fruition as planned. Examples include the federal government's FutureGen project in Illinois, the Southern Company's Kemper project, the Massachusetts Cape Wind project, the Texas Clean Energy Project (TCEP), and several nuclear plants proposed in the early 2000s during a period when many analysts expected a federal carbon price would be established and before directional drilling and fracking drove down the price of natural gas and wholesale electric prices.

While failure is an inevitable element of the innovation process, valuable lessons are often learned that can lead to later success in subsequent efforts and, over time, the rate of success can be improved. For early-stage technology innovators, patient capital to support piloting and project development activities over a 10-year or longer period, in contrast to the three- to five-year investment horizons of many investors today, could be immensely valuable. This would provide organizational and development stability through a series of technology readiness stages. For early-stage investors, providing that patient capital with a strategic view of technology characteristics that will be commercially valuable in deeply decarbonized energy markets can help guide the design and development of recent technologies in ways that will make them viable in competitive marketplaces, not just in an engineering lab. This may involve considering the value of designing generating technologies to have greater operational flexibility (for instance, to be "dispatched" up or down depending on the availability of wind and solar generation), sourcing equipment and components from overseas markets, initially demonstrating technologies in other countries before deploying them at scale in the U.S. and building the potential for export demand into business plans. The federal government, working in concert with technologists and investors, could offer expanded research and development funding through ARPA-E and the national laboratories, and support early commercial stage demonstration projects. (Gates, 2021) (National Academies of Sciences, Engineering, and Medicine, 2021) (Breakthrough Energy, IHS Market, Energy Futures Initiative, 2019)

Managing Existing Generation Fleets

The third challenge for business involves managing the nation's existing generation assets, in particular the large fleets of coal, natural gas, and nuclear power plants. The lack of sustainable energy policies at the federal level is a major source of risk for the owners of these power plants. Owners of merchant nuclear plants, those whose costs are not recovered through regulated rates, may view the lack of sustainable federal energy polices as wholesale markets not compensating them for the environmental

[12] This tax incentive is often referred to by the relevant section of the federal tax code, 45-Q.

value of zero-carbon generation. Owners of carbon-emitting coal and natural gas-fired power plants may see this as an opportunity to continue to operate their assets for an indeterminant number of years.

Nuclear

As of the end of 2020, the U.S. had a fleet of close to 100 nuclear reactors that generated slightly over half of all the zero-carbon energy produced during that year. The development of a new cohort of nuclear plants, once considered promising before the advent of natural gas fracking and decline of wholesale electric prices in the 2000s, is as of 2021 limited to the two reactors under construction at the Vogtle nuclear station in Georgia. The decline in wholesale electric prices across the country has contributed to the retirement of seven reactors between the beginning of 2013 and the beginning of 2019, with 12 more expected to retire by 2025. (U.S. Energy Information Administration, 2019) It has also imperiled the continued economic operation of other nuclear plants in regions with competitive wholesale markets, a risk that may grow over time with continued market penetration of renewable technologies that depress wholesale market prices. These concerns have pushed nuclear plant owners, policymakers concerned with maintaining employment and local tax bases, and environmental groups focused on preserving zero-carbon generation, to band together in support of state policies that would enable continued plant operations. (Clemmer, Richarson, Sattler, & Lochbaum, 2018) As of 2020, the states of New York, Illinois, Connecticut, and New Jersey have all adopted nuclear zero-emission credit (ZEC) systems to extend the operating lives of some plants in those states. These state initiatives along with recently passed federal policy supports are likely to be a major determinant of nuclear plant lives and carbon emissions in competitive market regions of the country. Most recent analyses of pathways to net-zero economy-wide greenhouse gas emissions envision the continued operation of the majority of today's nuclear fleet. Any development of new reactor capacity in the U.S. beyond the two now under construction will likely hinge on major advancements and cost reductions with next-generation technologies. As noted earlier, several companies are working on advanced reactor designs, and several are in the process of licensing next-generation technologies.

Coal

Over 30 percent of the country's coal-fired electric capacity was retired in the years leading up to 2020. However, coal still supplied 20 percent of U.S. electric generation in 2020 and, as of 2021, U.S. DOE forecasts estimate relatively modest declines in coal generation over the next five to ten years absent new policies.[13] At the same time, many deep decarbonization analyses forecast steep declines and the eventual elimination of this source of electricity by 2030 or soon thereafter.

To date, the uncertainty over new emission and energy policies has led owners of many coal-fired electric plants to continue to operate, albeit often with marginal economics and the risk of not recovering ongoing investments in plant and equipment or transfer their ownership to investment funds able and willing to bear the risk of continued operations. The decisions of plant owners to continue to invest and operate plants or move towards closure hinge on numerous business considerations that vary by region of the country, owner expectations for near term market conditions and competitor behavior, and form of power plant ownership. These include owner views of the likelihood and timing of federal or state clean energy or carbon pricing policies; other government policies that may tighten conventional air pollution, water and waste regulations which would increase power plant costs; commercial opportunities to repurpose

13 According to the U.S. EIA, the increase in natural gas prices during 2021 has caused gas-fired generation to decline and coal-fired generation to increase, but this effect is expected to be reversed within the next two years and be followed (absent new policies) by an extended period of modest declines in coal generation.

brownfield power plant sites for the production or support of low-carbon energy and other uses; the “real option value” of keeping economically marginal coal plants open because of the potential for higher natural gas and wholesale electric energy prices or near term advances in post-combustion CCS technologies; the incentive to continue to operate rate-regulated power plants with unrecovered investment costs still on their books in order to fully recover costs (unless otherwise addressed by securitization policies as in states like Colorado and New Mexico); the impact of must-take coal supply contracts and plant site remediation costs triggered by closure; and the interest of state policymakers and local communities in supporting local employment, tax bases and a “just transition” for communities currently hosting coal-fired power plants and related fuel facilities. All these contribute to complex and situation-specific plant management decisions.

Natural Gas

Now the single largest source of capacity, at roughly 40 percent, and energy, at roughly 35 percent, in the U.S. electric sector, natural gas power plants in some ways face similar issues as the owners of coal plants since the carbon emissions from natural gas generation will eventually need to be largely or fully eliminated to achieve net-zero emission goals. At the same time, the nation’s fleet of gas-fired combined cycle and combustion turbine plants has continued to grow each year in response to the need for new electric capacity and energy. Proposals to develop new gas-fired electric generation raise questions investors about the risk of stranded costs, that is, that these long-lived investments may be prematurely retired at some point in the future before their initial investment costs are fully recovered.

But to a greater extent than coal, electric generation from natural gas may have an important continuing role in a deeply decarbonized U.S. economy. This could come about as the result of advances in post-combustion carbon capture or commercialization of oxy-combustion technologies that would allow natural gas-fired power plants to generate energy with very low or perhaps even zero-carbon emissions. One example of this could be the Allam-Fetvedt cycle oxy-combustion technology, developed by 8 Rivers Capital and NET Power, which announced plans in 2021 to build their first commercial scale projects in Colorado and Illinois, with the Colorado project targeted for operation by 2025. (Bloomberg, 2021) Alternately, some currently operating combined cycle and combustion turbine plants (with upstream transport and storage facilities) might be retained indefinitely to provide reliability to the electric grid while being operated just 5 percent to 10 percent of the hours during the year. In this decarbonization pathway, these generating facilities may be fueled by natural gas (with the carbon emissions offset by other means such as use of land carbon sinks or direct air capture) or zero-carbon liquid fuels such as hydrogen. The technical or economic feasibility of such a low-utilization system of fuel production, transportation and generation has not yet been widely explored in the public literature.

Regulated Utilities and Diversified Electric Companies

The challenges just discussed apply to “pure play” companies and investors that focus exclusively on a single line of business such as developing central station solar PV plants, offshore wind plants or new transmission lines.

But many of the larger corporations in the U.S. electric sector are diversified enterprises that need to consider the impact of initiatives in one line of business on other parts of their business. Vertically integrated electric utilities have generation, transmission and distribution assets and will consider some of the issues outlined earlier about scaling commercial technologies and managing existing generating fleets in tandem with one another. Many utilities also often provide electric service in neighboring states, making them regulated by more than one state public utility commission with perhaps differing policy goals. For all these types of diversified companies, the challenges outlined before may be particularly complex to navigate.

To illustrate, rate regulated utilities are accountable to their state regulatory commissions and policymakers who are typically concerned with diverse policy objectives including service reliability, affordable electric rates, employment and local economic development, and ensuring a sustainable environment, among other goals. Clean energy and climate goals are part of this, but not the only important policy goal for many of these regulators. Utilities with ambitious clean energy and greenhouse gas emission reduction goals, including net-zero emission goals, take these other policy goals into account in their corporate planning efforts and weigh their tradeoffs. In the absence of a federal requirement mandating ambitious clean energy deployment or emission reductions, regulated utilities in states with supportive government policies will generally see more clean energy investment and better prospects for full cost recovery of prudent investments than utilities in states with less supportive government policies. The reverse may also often occur. A special case involves demonstrating advanced technologies with new and unfamiliar cost and performance risks. While clearly important to achieving climate goals from a national policy perspective, the technical and performance risks associated with demonstrating advanced technologies coupled with conventional cost-based electric utility regulation typically creates a financial disincentive for regulated utilities and their owners to invest in early-stage commercialization projects.[14]

Regulated utilities providing electric service from a single integrated generating system to adjoining states with state regulators that have conflicting policy priorities may face particularly difficult planning decisions and tradeoffs. Generating investments made to comply with the requirements or goals of one service area are likely to influence and perhaps raise the cost of providing electric service to an adjoining service area. For example, building new carbon-free generation to meet a RPS or CES requirement in one state could increase the utility's overall cost of generation, accounting for both the direct cost of the new resource and its impact displacing generation from other power plants. In some situations, total generation costs are allocated between the service areas based on their relative loads, leaving both service areas paying for a share of the costs resulting from one state's policy. This could lead to the need to separate the utility's integrated electric system on a jurisdictional basis, so that separate planning and system operations could be carried out in each state, with the costs resulting from each state's policies appropriately recovered from each state.

For corporations with both rate regulated and competitive lines of business, investments in transmission to move electricity from one region to another may influence the operations, emissions, economic value, and operating lives of generation assets. Large investments in distributed energy resources such as rooftop solar and batteries could similarly influence the value of central-station generation.

Closing

Looking forward over the coming decades, climate change is widely expected to spur a global transition to a cleaner, decarbonized energy system that must also be more resilient in the face of increasingly frequent extreme weather events.

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[14] Several electric utilities have incurred large financial disallowances associated with their efforts to develop new nuclear facilities (for example, The Vogtle and Sumner nuclear plants) and low-carbon fossil plants (for example, the Kemper coal CCS and Edwardsport IGCC projects).

To meet mid-century decarbonization goals, a step-change increase in the pace of clean energy deployment will be needed, leading to a doubling or tripling of the electric sector while fundamentally transforming its structure and operations.

For businesses in the electric sector, these changes will spur diverse and unprecedented investment opportunities, several times greater than in recent years. But at the same time, the energy transition also presents complex financial and organizational risks. These stem in large part from today's patchwork quilt of market and policy conditions across the country, the uncertainty of establishing sustainable national policies consistent with ambitious net-zero emission goals, the difficulty of rapidly scaling deployment and gaining consumer acceptance of new clean energy technologies, and the unknowns associated with the long-term mix of electric generation, storage and consumer technologies.

This points to three challenges for companies in the U.S. electric industry. The first is how to rapidly scale deployment of wind, solar, long-distance transmission and other technologies that have already been largely commercialized in some regions of the country. The second is how to rapidly commercialize advanced clean energy technologies such as carbon capture, zero-carbon liquid fuels, next-generation nuclear and firm renewables, which will be needed to fully decarbonize the economy in a reliable, affordable and socially acceptable way. The third is how to manage the existing generating fleets: to secure financial support for marginally economic nuclear plants or wind down their operation; to plan the retirement of coal plants or retrofit them with carbon capture; and to retrofit gas plants with carbon capture, retire them, or maintain them as low utilization generating resources to ensure electric reliability.

To address these challenges and succeed in this complex environment, successful electric businesses will need strategic foresight, the ability to critically assess regionally varied investment opportunities, and skills to manage large commercial and organizational risks. Core competencies will include constructively contributing to federal and state energy policies, developing new supply chains, reforming project siting and permitting practices, analyzing rapidly evolving electric markets and customer acceptance trends, assessing the commercial promise of emerging technologies, and managing commercial risks through contractual means, regulatory processes and financial scale.

Final note: In Greek mythology, Daedalus was a skilled craftsman who made wings for himself and his son Icarus so they could escape from the island of Crete. Daedalus was careful not to fly too high or too low and made the trip safely. But despite his father's warning, Icarus flew too high. The heat of the sun melted the wax used to make the wings, causing Icarus to fall into the sea and drown.

References

Bloomberg. (2021, April 15). *U.S. Startup Plans to Build First Zero-Emission Gas Power Plants*. Retrieved August 2020, 2021, from Bloomberg Green: https://www.bloomberg.com/news/articles/2021-04-15/u-s-startup-plans-to-build-first-zero-emission-gas-power-plants

Bolinger, M., Seel, J., Warner, C., & Robson, D. (2021). *Utility-Scale Solar, 2021 Edition.* Lawrence Berkeley National Laboratory. Retrieved August 20, 2021, from https://emp.lbl.gov/sites/default/files/2020_utility-scale_solar_data_update.pdf

Breakthrough Energy, IHS Market, Energy Futures Initiative. (2019). *Advancing the Landscape of Clean Energy Innovation.* Breakthrough Energy. Retrieved August 20, 2021, from https://www.breakthroughenergy.org/reports/advancing-the-landscape/

CATF. (2021, November 15). *Infrastructure Investment and Jobs Act: A Downpayment for Fullfilling Federal Promises on Climate Action*. Retrieved from Clean Air Task Force: https://www.catf.us/resource/infrastructure-investment-jobs-act-a-down-payment-on-fulfilling-federal-promises-for-climate-action/

Clemmer, S., Richarson, J., Sattler, S., & Lochbaum, D. (2018). *The Nuclear Power Dilemma: Declining Profits, Plant Closures, and the Threat of Rising Carbon Emissions.* Union of Concerned Scientists. Union of Concerned Scientists. Retrieved August 20, 2021, from https://www.ucsusa.org/resources/nuclear-power-dilemma

Edison Electric Institute. (2020). *2019 Financial Review - Annual Report of the U.S. Investor-Owned Electric Utility Industry.* EEI. Retrieved August 20, 2021, from https://www.eei.org/issuesandpolicy/Finance%20and%20Tax/Financial_Review/FinancialReview_2019.pdf

Gates, B. (2021). *How to Avoid a Climate Disaster, The Solutions We Have and the Breakthroughs We Need.* New York: Alfred A Knopf.

Goff, M. (2017, July 13). *How Natural Gas and Wind Decarbonize the Grid*. Retrieved from The Breakthrough Institute: https://thebreakthrough.org/issues/energy/how-natural-gas-and-wind-decarbonize-the-grid

IPCC, M.-D. V. (2021). *IPCC, 2021: Summary for Policymakers. In Climate Change 2021: The Physical Science Basis. Contributions of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press.

Larson, E., Greig, C., Jenkins, J., Mayfield, E., Pascale, A., Zhang, C., . . . Swan, A. (2020). *et-Zero America: Potential Pathways, Infrastructure, and Impacts, interim report.* Princeton: Princeton University. Retrieved August 20, 2021, from https://environmenthalfcentury.princeton.edu/sites/g/files/toruqf331/files/2020-12/Princeton_NZA_Interim_Report_15_Dec_2020_FINAL.pdf

Lazard. (2020, October 2020). *Levelized Cost Of Energy, Levelized Cost Of Storage, and Levelized Cost Of Hydrogen.* Retrieved August 20, 2021, from Lazard.com: https://www.lazard.com/perspective/lcoe2020

Lott, M., & Phillips, B. (December 2021). *Advancing Corporate Procurement of Zero-Carbon Electricity in the United States: Moving from RE100 to ZC100.* New York: Columbia University CGEP.

National Academies of Sciences, Engineering, and Medicine. (2021). *The Future of Electric Power in the United States.* Washington DC: The National Academies Press. Retrieved August 20, 2021, from https://www.nap.edu/catalog/25968/the-future-of-electric-power-in-the-united-states

Nuclear Innovation Alliance. (2021, August 20). *Industry Innovation Leadership Council*. Retrieved from Nuclear Innovation Alliance: https://nuclearinnovationalliance.org/industry-innovation-leadership-council

Phillips, B., & Reilly, J. (2019, February). Designing Successful Greenhouse Gas Emission Reduction Policies: A Primer for Policymakers – The Perfect or the Good? *MIT Joint Program Report Series, 335*. Retrieved from https://globalchange.mit.edu/publication/17200

Place, A. (2020). *State and Uility Decarbonization Committments*. Retrieved June 17, 2021, from https://www.catf.us/2020/10/state-and-regional-decarbonization-commitments/

RE100. (2020). *RE 100 Annual Progress and Insights Report*. Retrieved August 20, 2021, from file:///C:/Users/BPHILL~1/AppData/Local/Temp/RE100%20Annual%20Report%202020.pdf

RE100. (2021). *RE100 members' electricity and renewable electricity consumption by market*. Retrieved August 20, 2021, from https://www.there100.org/about-us

RGGI. (2021, December 29). Retrieved from The Regional Greenhouse Gas Initiative: https://www.rggi.org/

Sustainable Development Solutions Network. (2020). *Zero Carbon Action Plan.* New York: Sustainable Development Solutions Network (SDSN). Retrieved August 20, 2021, from https://irp-cdn.multiscreensite.com/6f2c9f57/files/uploaded/zero-carbon-action-plan%20%281%29.pdf

TCI. (2021, December 29). Retrieved from Transportation and Climate Intiative: https://www.transportationandclimate.org/

The NorthBridge Group. (2021, April 20). *Review and Assessment of Literature on Deep Decarbonization n the United States: Importance of System Scale and Technological Diversity*. Retrieved from Clean Air Task Force: https://www.catf.us/wp-content/uploads/2021/06/NorthBridge_Deep_Decarbonization_Literature_Review.pdf

The White House. (2021a, January 27). *Executive Order on Tackling the Climate Crisis at Home and Abroad*. Retrieved August 20, 2021, from The White House: https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/

The White House. (2021b, April 22). *FACT SHEET: President Biden Sets 2030 Greenhouse Gas Pollution Reduction Target Aimed at Creating Good-Paying Union Jobs and Securing U.S. Leadership on Clean Energy Technologies*. Retrieved August 20, 2021, from The White House: https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/

U.S. Energy Information Administration. (2019, March 21). *Despite Closures, U.S. Nuclear Electricity Generation in 2018 Surpassed its Previous Peak*. Retrieved August 20, 2021, from U.S. Energy Information Administration: https://www.eia.gov/todayinenergy/detail.php?id=38792

U.S. Energy Information Administration. (2020). *U.S. Energy-Related Carbon Dioxide Emissions, 2019*. Retrieved August 20, 2021, from U.S. Energy Information Administration: https://www.eia.gov/environment/emissions/carbon/pdf/2019_co2analysis.pdf

U.S. Energy Information Administration. (2021a, August 20). *U.S. Natural Gas Citygate Price*. Retrieved from U.S. Energy Information Administration: https://www.eia.gov/dnav/ng/hist/n3050us3A.htm

U.S. Energy Information Administration. (2021b). *Short-Term Energy Outlook.* US Department of Energy. Retrieved August 20, 2021, from https://www.eia.gov/outlooks/steo/archives/jun21.pdf

U.S. Energy Information Administration. (2021c, August 20). *Annual Energy Outlook - 2020 data from interactive table*. Retrieved from U.S. Energy Information Administration: https://www.eia.gov/outlooks/aeo/data/browser/

U.S. Energy Information Administration. (2021d). *Battery Storage in the United States: An Update on Market Trends.* Washington DC: U.s Department of Energy.

Williams, J. H., Jones, R. A., H. B., K. G., Hargreaves, J., F. J., & M.S., T. (2021, January 14). Carbon□Neutral Pathways for the United States. *AGU Advances, 2*(1). Retrieved August 20, 2021, from https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020AV000284

Wiser, R., Bolinger, M., Hoen, B., Millstein, D., Rand, J., Barbose, G., . . . Paulos, B. (2021). *Land-Based Wind Market Report: 2021 Edition.* Lawrence Berkeley National Laboratory. Retrieved August 20, 2021, from https://emp.lbl.gov/sites/default/files/2020_wind_energy_technology_data_update.pdf