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Climate Strategy Assessments for the U.S. Electric Power Industry

Assessing Risks and Opportunities Associated with a 2-Degree Transition and the Physical Impacts of Climate Change

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About this Study

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www.ceres.org/Electric2DS

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Our multi-national client base includes electric and natural gas utilities, major transportation fleet operators, clean technology firms, environmental groups and government agencies.

We bring insights to executives, operating managers, and advocates. We help you find opportunity in environmental markets, anticipate and respond smartly to changes in administrative law and policy at federal and state levels. We emphasize both vision and implementation, and offer timely access to information along with ideas for using it to the best advantage.

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EXECUTIVE SUMMARY

The electric power industry is one of the largest sources of greenhouse gas (GHG) emissions in the U.S.[1] It is also the most capital-intensive industry in the U.S, with infrastructure and operations uniquely vulnerable to climate change risks.[2] As these risks grow and become more apparent, companies in the electric power industry are facing increased demands from investors and other stakeholders to understand how they are addressing and mitigating these risks in their investment decisions and overall business strategies. Investors want to know if management teams have fully accounted for the potential pace and scale of change associated with reducing GHG emissions from electricity and energy operations as well as those needed to prepare for the physical impacts associated with climate change.

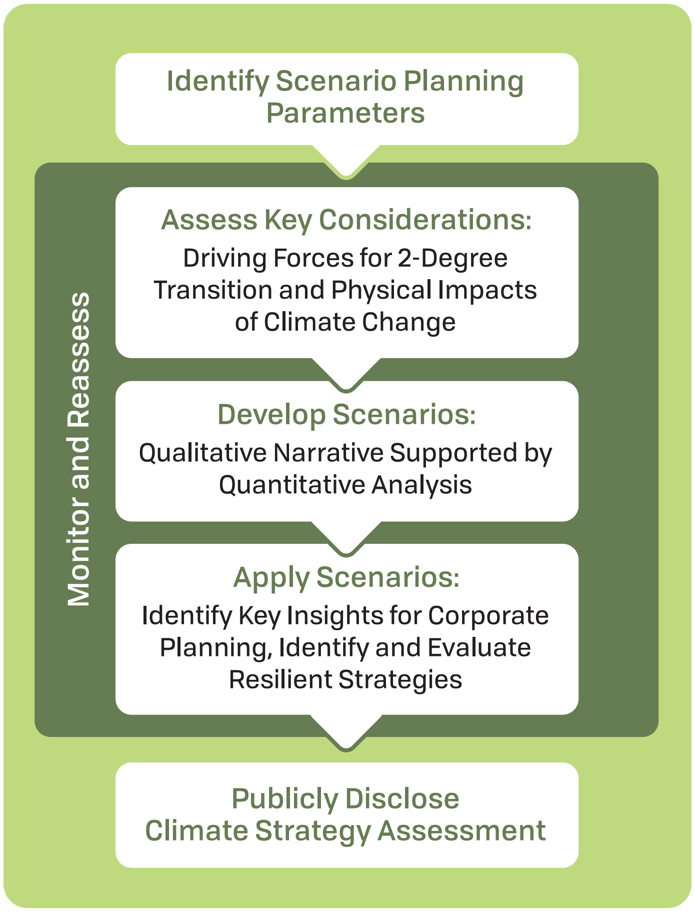
In 2017, shareholders of nine companies in the electric power industry filed resolutions calling on companies to undertake analyses that would examine the business impacts of policies and market changes that would drive GHG emissions reductions to levels consistent with limiting global temperature rise to below two degrees Celsius (a commonly accepted benchmark for climate change mitigation activities). There is a growing level of engagement on this topic across the industry.[3] Spurred by increased investor focus, several organizations have developed recommendations and guidance for companies to consider when assessing climate risks and opportunities. Most notably, the Financial Stability Board's Task Force for Climate-Related Financial Disclosures (TCFD) released recommendations in 2017. TCFD and similar investor initiatives are urging companies to disclose how they are assessing and planning for the potential effects of climate change within their core business operations.

This framework was commissioned by Ceres to provide specific guidance for assessing climate change-related risks and opportunities for companies in the U.S. electric power industry.* Building on existing literature, the framework outlines an approach for developing a climate strategy assessment, which consists of two primary components:

1) a scenario analysis that reflects a) the transition in the U.S. electric power industry and across the economy that would be necessary to reduce emissions consistent with limiting global temperature rise to below 2-degrees Celsius (often called a "2-degree scenario" analysis) and b) the potential physical impacts associated with climate change; and
2) the application of scenario analysis insights to inform business strategy.

This framework highlights key questions and considerations for companies when conducting these assessments to support internal business planning and to meet investor and stakeholder expectations. The framework is structured around the components of a climate-related assessment **(summarized in Figure ES-1)** with detailed appendices that provide further context and references.

Figure ES-1. Climate Strategy Assessment Framework



* The electric power industry includes a range of different business structures, including independent power producers, investor-owned utilities, municipally-owned utilities and cooperative utilities. Throughout this document, the term "company" is used to describe the entity conducting the analysis but the term is intended to refer to any of the different business structures, including municipally-owned utilities and cooperative utilities.

Table ES-1: Key Factors to Consider in 2-Degree Transition and Physical Impacts Scenario Development

2-DEGREE TRANSITION	PHYSICAL IMPACTS
· GHG emission reduction trajectory (e.g., 80 percent reduction in U.S. economy-wide net emissions by 2050, 90 percent reduction in emissions from U.S. electric sector) · Electrification of end-uses · Advances in energy efficiency · Pace of deployment of energy technologies, including carbon capture and sequestration (CCS), nuclear, solar, wind, and battery storage · Policies for clean energy and electricity markets · Consumer expectations and corporate procurement · Growth of distributed electricity	· Temperature and extreme heat · Water availability and precipitation patterns · Sea level rise · Extreme precipitation events, hurricanes, tropical storms, and coastal storm surge · Wildfires · Changes in wind patterns

Assess Key Considerations and Develop Scenarios

Many of the organizations and stakeholders calling for more public disclosure on climate change-related risks and opportunities request that companies use "scenario analyses" to inform their planning and reporting. Scenario analysis is a method for assessing the potential implications of a range of hypothetical future states of the world.[4] It allows organizations to consider outcomes based on unpredictable factors that could play out over a medium to long time horizon and that could significantly affect their business outlook.[5] As such, this type of analysis is well-suited for exploring the questions associated with the potential effects of a 2-degree transition and the impacts of climate change, both of which are uncertain and could follow a variety of paths. By following a structured process, a company can assess a range of factors to better understand the magnitude and variability of potential influence that each may have on future business conditions. Table ES-1 summarizes important factors to consider in developing scenarios relating to 2-degree transitions and the physical impacts of climate change. A key factor for 2-degree transition scenarios is the assumption of future GHG emissions. Reflecting the range and costs of emission reduction opportunities available to the U.S. electric power industry, most modeling suggests the industry would need to reduce emissions at least 90 percent from 1990 levels by 2050 for the U.S. to achieve an 80 percent reduction.

Apply Scenarios to Corporate Planning

Assessing the implications of a 2-degree transition and the physical impacts of climate change through scenario planning strengthens a company's assessment of future risks and opportunities for the business, preparing a company to adapt and prosper in an uncertain future. However, the full value of a climate strategy assessment is predicated on how a company identifies and applies the insights from scenario analyses to its business planning process. Rigorous assessments ensure that a company is fulfilling its obligations to shareholders, as well as other investors, customers, and external stakeholders. Accordingly, businesses should take the information gleaned from scenarios to identify vulnerabilities and opportunities affecting their bottom-line or impacting quality of service. Table ES-2 provides examples of risks and opportunities for companies in the U.S. electric power industry to consider, broken out by industry segment.

Publicly Disclose Climate Strategy Assessments

Finally, investors and stakeholders want to understand how companies apply their climate strategy assessment to inform company planning and strategies. Thorough disclosures include an objective assessment of the material risks and opportunities identified through the assessment and an articulation of how a company manages these uncertainties. Companies should bring

Table ES-2. Examples of Potential Business Risks and Opportunities

INDUSTRY SEGMENT	RISKS	OPPORTUNITIES
Overarching	· Reputation risk from carbon-intensive portfolios · Higher insurance premiums, reduced access to capital due to discrete and recurring costs from extreme weather events or chronic climate impacts · Increased shareholder concern and divestment · Exposure to costs associated with complying with federal, state and local policies	· Market opportunities for innovation achieved through R&D · Growth through electrification and delivering low-carbon energy services · Opportunities for improving efficiencies and reliability and lowering overall costs by investing in more resilient, smart grid, and low carbon technologies · Reputational benefits associated with clean energy leadership
Power Generation	· Forced early-retirement, stranded assets, loss of value of existing generation resources · Reduced revenue streams from changing supply and demand profiles · Increased discrete and recurring costs from extreme weather events or chronic climate impacts · Insufficient incentives from competitive market structures for new, low-carbon investments	· Increased demand for new, low-carbon generation · Business opportunities supplying resources with specific attributes (e.g., flexibility) that will be valued in markets with changing supply and demand profiles · Business opportunities delivering renewables and low-carbon generation to customers (e.g., commercial and industrial customers, community-based buyers) · Diversification of assets
Transmission	· Power plant retirements and changes in supply and demand profiles could reduce value of existing assets · Costs associated with hardening the electric grid to physical impacts, which may include moving assets to less vulnerable locations or making transmission and distribution resilient · Increased discrete and recurring costs from extreme weather events or chronic climate impacts	· Demand for new transmission assets to connect renewable resources with demand centers · New business models that create additional value for transmission assets
Distribution Utilities	· Effectively managing local grid (i.e., maintaining safety, affordability, and reliability) in face of increasing availability of distributed energy resources and customer demands · Insufficient revenue models to accommodate greater penetration of distributed energy resources and energy efficiency · Costs associated with hardening grid to physical impacts, which may include moving assets to less vulnerable locations or making transmission resilient to wildfires · Increased discrete and recurring costs from extreme weather events or chronic climate impacts	· New demand associated with electrification of end-uses (e.g., electric vehicles or industrial electrification) or associated with increased demand for air conditioning · Greater value for distribution assets due to expanding scope of electrification · Reduced costs to consumers through efficiency gains · Greater efficiencies through load shifting · Improved reliability through investments in smart and resilient grid technologies (e.g., benefits of energy storage technologies such as battery storage) · Improved consumer reputation benefits for clean and resilient grids

together the elements of their assessment, including the process steps, scenario parameters and assumptions, and risks and opportunities summarized in the sections and tables above, into a public report. **Table ES-3** summarizes key elements to communicate in such a report. As more companies develop and publish climate-related assessments and companies and stakeholders become more versed in the process of developing and interpreting the results, these key elements could be refined.

Table ES-3. Effectively Communicating Climate Strategy Assessments

ASPECT OF ASSESSMENT	PARAMETER	KEY ELEMENTS TO COMMUNICATE
Overarching	Geographic Scope	· Area of operations included in assessment · Operations not included in assessment
	Macroeconomic Inputs	· Population, demographics, economic growth, and other key factors
	Time Horizon	· Period covered by quantitative modeling · Period covered by qualitative assessments
	Covered Assets	· Assets included in the assessment · Assets not included in the assessment
	Process	· Internal process for developing scenarios and identifying physical impacts, informing company strategy, monitoring changing landscape, and engaging senior leadership
2-Degree Transition	Emission Reduction Trajectory	· Justification for reduction trajectory (existing modeling suggests the U.S. electric power industry would have to reduce emissions by about 90% by 2050) · Potential pace of emission reductions
	Electricity Demand	· Potential impact of energy efficiency, energy storage, electric vehicles, distributed energy technologies, and other key factors on demand, including how it affects load peaks
	Energy Technologies	· Outlook for future energy resources · Assumptions for fuel and technology costs, including both demand and supply-side · Generation and capacity of energy supply resources · Role of fossil fuel-based generation (with and without carbon capture and storage)
	Consumers, Policies and Market Structures	· Assumptions for consumer preferences · Role and assumptions for policy and market structures · Implications of policy and market assumptions on technology preferences and on costs
Physical Impacts	Acute Impacts	· Exposure of assets to short-term impacts including extreme heat, extreme precipitation and storms, storm surge, wildfires, and other potential acute climate impacts
	Chronic Impacts	· Exposure of assets to long-term impacts including increased temperatures; sea level rise; changes in precipitation patterns, water availability, and wind patterns; and other potential chronic climate impacts
Business Insights (Based on TCFD Recommended Disclosures)	Strategy	· Describe the climate-related risks and opportunities the company has identified over the short, medium, and long term · Describe the impact of climate-related risks and opportunities on the company's businesses, strategy, and financial planning · Describe the resilience of the company's strategy, taking into consideration different climate-related scenarios, including a 2-degree scenario
	Risk Management	· Describe the company's process for identifying and assessing climate-related risks · Describe the company's processes for managing climate-related risks · Describe how processes for identifying, assessing, and managing climate-related risks are integrated into the organization's overall risk management

1. INTRODUCTION

From deployment of distributed energy resources to investment in resilient infrastructure to retirement of older generating resources, the U.S. electric power industry is experiencing rapid change. While many factors are contributing to this transformation, concerns over climate change are a defining element. The electric power industry has the distinction of being one of the largest sources of greenhouse gas (GHG) emissions in the U.S. while also the most capital-intensive industry.[6] The industry's capital investments exceed $100 billion per year.[7] It is not surprising that companies in the electric power industry are facing increased demands from investors and other stakeholders about how they are incorporating climate risks into their investment decisions and overall business strategies. Investors want to know if management teams have fully accounted for the potential pace and scale of change associated with decarbonizing electricity and energy more broadly, and the physical impacts associated with climate change. As S&P Global recently noted, "[f]ailing to adapt to change could leave some utilities open to adverse regulatory scrutiny, more vulnerability to load loss due to distributed generation or battery technologies, and in the extreme, stranded investments."[8]

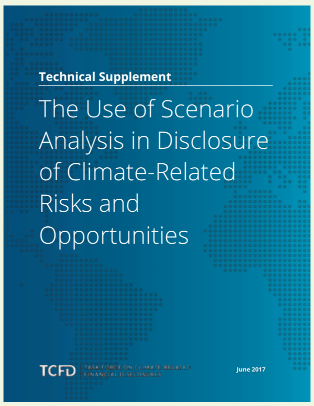
Lowering GHG emissions to a level that constrains warming to below 2 degrees would require a substantial restructuring of the global energy system.* According to the International Energy Agency (IEA), the scale of the restructuring is equivalent to diverting $40 trillion in investments away from fossil fuels to low-carbon energy and investing an additional $35 trillion in energy-efficiency.[9] In the U.S. electric power industry, it would require investments in clean energy technologies that significantly exceed current trends and expose companies to policies that impact revenue and valuation of assets. At the same time, companies in the U.S. electric power industry must cope with changing physical conditions associated with climate change. In 2017 alone, three of the most powerful hurricanes on record hit the U.S., inundating refineries and power generating stations, forcing wind and nuclear curtailment, and downing transmission lines. Hurricane Maria so severely damaged Puerto Rico's electric grid that 90 days after making landfall, only 65 percent of electricity service had been restored.[10]

With these risks coming into greater focus, shareholders of nine companies in the electric power industry filed resolutions in 2017 calling on the companies to undertake analyses that would examine the business impacts of policies and market changes that would be consistent with limiting global temperature rise to well below 2 degrees. Eight of the resolutions received more than 40 percent support and the ninth, filed at PPL Corporation (PPL), received a majority vote of 57 percent.† In response, PPL published a corporate climate assessment in December

* Throughout this document, unless otherwise noted, temperatures and degrees are measured in Celsius. There are varying perspectives on what constitutes a trajectory that is consistent with 2 degrees. Some have interpreted this as a 66 percent chance of staying below 2 degrees while others look at scenarios that provide a 50 percent chance of staying below 2 degrees. Further, there is debate about what constitutes global ambition to stay "well below 2 degrees," language that countries of the world agreed to under the Paris Agreement. The clause, "Well below 2 degrees" has been interpreted to mean an 80 percent chance of staying below 2 degrees and greater than 50 percent chance of constraining warming to 1.5 degrees.

† Resolutions were filed and voted on at AES Corporation, Ameren, Dominion, DTE Energy, Duke Energy, FirstEnergy, PPL, PNM, and Southern Company. Resolutions were also filed but withdrawn at NRG and Xcel. Ceres maintains an database of information on shareholder resolutions and other engagement at: https://engagements.ceres.org/.

2017 followed by a January 2018 announcement to cut the company's carbon dioxide emissions 70 percent from 2010 levels by 2050.[11] In March 2018, Duke Energy also released the results of a two-degree scenario analysis.[12] There is a growing level of engagement on this topic across the industry. Spurred by increased investor focus, several organizations have developed recommendations and guidance for companies to consider when conducting climate risk analyses. Most notably, the Task Force for Climate-Related Financial Disclosures (TCFD) released recommendations in 2017 on assessing and reporting risks associated with climate change. TCFD and related investor initiatives are urging companies to disclose how they are assessing and planning for the potential effects of climate change within their core business operations.



The Task Force for Climate-Related Financial Disclosures (TCFD)

In 2015, in response to growing interest from the investor community, the Financial Stability Board, an international body that monitors and makes recommendations about the global financial system, created TCFD as a working group to develop guidelines for how companies should assess and report their climate-related risks in financial-disclosure documents.

In recent years, the Financial Stability Board has grown concerned that a lack of information about how economic impacts posed by climate change and the economic shifts associated with transitioning to a low-carbon future could put companies and their underwriters at risk. The Financial Stability Board has stated that improved reporting would "enable stakeholders to understand better the concentrations of carbon-related assets in the financial sector and the financial system's exposures to climate-related risks." Such disclosures would allow investors, lenders, insurance underwriters, credit rating agencies, stock exchanges, and investment consultants to make more informed investment, crediting, and insurance decisions.

TCFD published its final recommendations in June 2017, providing guidance for scoping and assessing climate-risks and for developing, implementing, and reporting internal response measures to improve company resilience against these risks. Its recommendations are aimed at promoting a better understanding of a company's risk management and decision-making process at every level. As of February 2018, the TCFD website lists 240 organizations that support the recommendations and sixteen financial institutions are working to adopt key elements of the TCFD recommendations as part of a pilot project under the U.N. Environmental Program Financial Initiative.

Consistent with the scope of this framework, the TCFD stresses the importance of using scenarios to better understand planning for a 2-degree transition and the physical impacts of climate change. Both the TCFD report and its technical supplement on the use of scenario analysis are helpful reference documents for companies in the U.S. electric power industry and other industries that are developing climate-related assessments.

References:

Financial Stability Board Task Force on Climate-Relate Financial Disclosures (TCFD), "Final Report: Recommendations of the Task Force on Climate-Related Financial Disclosures", June 29, 2017. Available at: https://www.fsb-tcfd.org/publications/final-recommendations-report/.

TCFD, "Technical Supplement: The Use of Scenario Analysis in Disclosure of Climate-related Risks and Opportunities", June 2017. Available at: https://www.fsb-tcfd.org/publications/final-technical-supplement/.

This framework was commissioned by Ceres to build on existing literature, including the TCFD recommendations, and to provide more detailed guidance specific to companies in the U.S. electric power industry. The electric power industry includes a variety of business structures, including independent power producers, investor-owned utilities, municipally-owned utilities, and cooperative utilities. Throughout this document, the term "company" is used to describe the entity conducting the analysis but the term is intended to refer to any of the different business structures, including municipally-owned utilities and cooperative utilities. These companies own and operate a range of assets, including companies that primarily operate systems to distribute electricity to customers and companies that operate power plants that generate electricity.

To assist companies in the electric power industry in assessing their potential exposure to transition and physical risks and to identify potential business opportunities, this report lays out a framework for companies to conduct climate strategy assessments that consists of two primary components:

1) a scenario analysis that reflects:
   a. the transition in the U.S. electric power industry and across the economy that would be necessary to reduce emissions consistent with limiting global temperature rise to below 2 degrees, and
   b. the potential physical impacts associated with climate change; and
2) the application of scenario analysis insights to inform business strategy.

This guidance is intended to help companies examine a broad range of climate change-related factors impacting the U.S. electric power industry and account for them as appropriate within business strategies. In addition to helping shape company strategy, climate-related assessments can also help inform disclosures with investors, policymakers, customers, and other key stakeholders. This framework provides guidance to assist companies in developing reports that fulfill the expectations of investors and stakeholders. It includes an overall framework for developing an assessment and identifies specific considerations to support robust and in-depth analyses. With increased investor attention, companies in the U.S. electric power industry are devoting more resources to climate strategy assessments.

This framework provides guidance to assist companies in developing reports that fulfill the expectations of investors and stakeholders. It includes an overall framework for developing an assessment and identifies specific considerations to support robust and in-depth analyses. With increased investor attention, companies in the U.S. electric power industry are devoting more resources to climate strategy assessments.

Recognizing that companies are at various stages in assessing and reporting on climate-related risks and opportunities, this framework is intended to provide support across the continuum. The report is structured in a manner that corresponds to major components of a climate strategy assessment:

- Section 2 provides context for using scenarios as part of climate-related assessments;
- Section 3 describes key considerations for companies for incorporating the transition implied by a 2-degree target into scenarios;
- Section 4 describes key considerations for companies for incorporating the potential physical impacts of climate change into scenarios;
- Section 5 provides guidance for applying insights gained through scenarios into a company's business strategy;
- Section 6 reviews the elements that companies could include to fulfill reporting expectations of the public and investors;
- Appendix A provides a deeper review of the resources available to understand the transition implied by a 2-degree target and how to undertake a 2-degree transition scenario analysis;
- Appendix B provides a deeper review of the tools that have been developed to assist in evaluating the potential physical impacts of climate change; and
- Appendix C includes a consolidated list of key resources.

Throughout the report, case studies provide examples of the work being done by companies to respond to stakeholder questions and to identify the potential risks and opportunities associated with climate change.

2. SCENARIO ANALYSIS FOR CLIMATE STRATEGY ASSESSMENTS

Scenario analysis is a long-standing tool used by many energy companies to explore how different driving forces could shape future business conditions and affect a company's competitiveness. This approach is well-suited for exploring the uncertainties and possible effects associated with climate change. Scenario analysis serves as the analytical foundation for a climate strategy assessment. Many of the organizations and stakeholders calling for more public disclosure on climate change-related risks and opportunities request that companies use scenario analyses to inform their planning and reporting.[13]

Scenario analysis is a method for assessing the potential implications of a range of hypothetical future states of the world.[14] It allows organizations to consider outcomes based on unpredictable factors that could play out over a medium to long time horizon and that could significantly affect their business outlook.[15] Natural disasters, geopolitical events, technological revolutions, and changing customer preferences are examples of factors that could reshape the future landscape. Within the electric power industry, there are numerous examples of unexpected shifts having a significant impact on market conditions. Consider the impacts of the demonstration and rapid adoption of hydraulic fracturing on the natural gas supply outlook, the Fukushima earthquake on global nuclear assets, or the Great Recession of 2007-2009 on U.S. electricity demand. Each of these changes dramatically reshaped future business conditions.

Scenarios are not intended to predict the future, nor can (or should) businesses fully mitigate the potential costs or expect to benefit from the potential opportunities associated with every future uncertainty. However, by embracing a robust scenario planning process, organizations can sharpen their critical thinking and strengthen their strategic planning. It helps avoid blind spots and the trap of not challenging conventional wisdom. Importantly, scenario analysis provides an opportunity to test out how business strategies may fare and can help to identify key uncertainties and driving forces that could have a significant impact on a company's business outlook. By advancing these capabilities, organizations are better positioned to develop more resilient business strategies. This process can lead to the consideration or even preparation of alternate business strategies and contingencies.

Scenario planning and the overall assessment process can bring significant value to an organization but it requires careful planning and an investment of time and resources. To be instructive, well-constructed scenario analyses follow a methodical process to assess and develop scenario building blocks.[16] While a first step is generally to define the specific focus or business decision that will be evaluated through scenario analysis, this framework focuses on scenarios designed to explore uncertainties associated with climate change. Two additional questions closely aligned with the focal issue for the scenario analysis are the appropriate time horizon and geographic scope of the analysis.

The importance of setting an appropriate time scale for evaluation is a consistent theme across scenario analysis literature.[17,18,19] The characteristics of the electric power industry dictate that companies use a relatively long planning horizon. Electric-industry assets require significant capital expenditures that have extended payback periods and are especially vulnerable to shifts in policy and technology development that may occur within that time scale. Many of the assets have long lead times for construction, and are long lived. Fossil fuel power plants have lifetimes spanning between 30 and 60 years.[20] This means that decisions made in the coming decade will have lasting impacts for companies and the broader electric system.

Twenty-year analyses where companies in the electric power industry quantitatively assess future market fundamentals are common across the industry and this is an appropriate starting point for a detailed scenario as part of a climate-related assessment. However, longer-term qualitative assessments that extend beyond twenty years (e.g., through 2050 or beyond) can provide valuable insights and considerations. Such longer-term assessments can be used to develop insights to inform the potential degree of change to be assessed in shorter-term quantitative analyses. For example, a projection of a two-foot sea level rise by 2050 does not imply that this rise would only occur in 2050, but rather, assets in low-lying coastal areas may experience a steady increase in risk of flooding over the coming decades. Similarly, examining a 2-degree transition to 2050 provides a greater understanding of interim targets and market changes that may be necessary in 2030 or 2040 to meet overall GHG goals. Climate assessments for the electric power industry should include both quantitative and qualitative assessments with a time horizon that extends through 2050 or beyond.

Defining the geographic scope is another critical element in the development of scenarios. Too limited a scope may exclude important factors that would be relevant for the company to consider. For example, the competitiveness of many electric generation technologies will be shaped by global investment levels. Closer to home, a company could be affected by climate change-induced supply chain disruptions that extend outside its typical service or market area but nevertheless have significant impacts on operations. It is important to consider how regional or local elements of a scenario correlate with broader industry and geopolitical trends. Therefore, a company should strive to consider the full range of its assets and products in its analysis but may also want to consider broader trends that affect entire regions and the electricity grid.

With basic parameters for the scenarios established, the next critical step is to identify, assess, and construct relevant driving forces that will define each scenario. Scenarios are typically formed by a set of driving forces that are assembled into a scenario narrative that explains how a series of conditions and events can logically lead to a future state that is very different from current business conditions. Sections 3 and 4 of this report respectively address considerations for incorporating a 2-degree transition and the physical impacts of climate change into a scenario. The important factors highlighted in these sections and in more detail in Appendices A and B provide a starting point for a company to assess the most important driving forces to incorporate into scenarios. Informed by internal subject matter experts and external resources, a company can critically examine the degree to which these different factors may influence the future.

There are a variety of methods that can be used to facilitate the scenario planning process. The most effective assessments integrate input across all aspects of business operations and have buy in from subject matter experts as well as corporate executives. By following a structured process, a company can characterize the driving forces to better understand the potential influence that different considerations may have on future conditions. A company can work to identify driving forces that have a high likelihood of happening (predetermined elements) and forces that are both uncertain and potentially impactful on the company's future business conditions (critical uncertainties). A rigorous analysis will generally show that the number of predetermined elements a company can expect is relatively small. Demographic changes for an electric utility's existing customer base is one potential example. And while the future is uncertain, a methodical and objective process of evaluating driving forces can help a company identify uncertainties that could significantly impact future conditions. Through this process, a company will examine how these critical uncertainties could plausibly unfold in the future and how they could influence future conditions in a specific scenario. Scenario planning relies on an iterative process of evaluating these considerations, testing assumptions and assessing potential impacts, and ultimately constructing qualitative scenario narratives supported by quantitative market analyses that explore potential future business conditions.

While the future is uncertain, a methodical and objective process of evaluating driving forces can help a company identify uncertainties that could significantly impact future conditions.

Once developed, scenarios provide a valuable resource to visualize and quantify a range of potential future states. At the same time, the process of constructing scenarios can provide deep insights into factors that will influence changing business conditions. However, realizing the full benefits of scenarios is predicated on how a company actively applies insights gained from the process and how it operationalizes certain aspects of the process to continually monitor external factors and adjust its strategy as appropriate. The final two sections of this report address these important steps. Section 5 addresses the use of scenarios to identify and apply insights to support a company's investment decisions and overall strategy and Section 6 addresses the important role of publicly disclosing key assumptions and findings of these analyses to inform investors and other stakeholders.

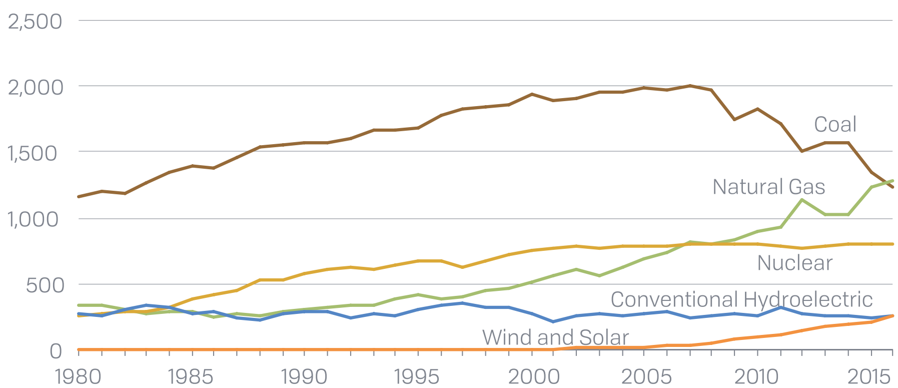
3. KEY CONSIDERATIONS FOR INCORPORATING A 2-DEGREE TRANSITION INTO A SCENARIO

A transition to lower carbon technologies is already reshaping the U.S. electric power industry. Coinciding with the start of the shale gas revolution, coal generation peaked in the U.S. in 2007 and has since rapidly declined **(see Figure 3.1)**. In 2016, annual electricity generation from coal dropped to its lowest level since the early 1980s. That same year, natural gas overtook coal as the nation's largest source of electricity for the first time in history.[21] Coal-fired power plants continue to retire, with 29 coal units retired in 2017 and another 54 scheduled to retire in 2018 and 2019.[22]

At the same time, renewable energy capacity has grown dramatically. Together, wind and solar accounted for 62 percent of capacity additions in 2016.[23] The U.S. solar industry added almost 15 gigawatts (GW) of solar capacity in 2016 and close to 12 GW in 2017. The additions represent a sharp upward trend, almost half of all U.S. solar capacity (54 GW) has been installed in the last two years.[24] Wind generation has also experienced record growth and now has an installed capacity of more than 89 GW.[25] A number of factors are driving demand for renewable energy including decreased costs of wind and solar technologies, federal and state tax incentives, state renewable portfolio standards, and changes in customer preferences. Many large consumers of electricity are now pursuing renewable energy procurement. For example, 128 companies have committed to 100 percent renewable electricity through an initiative called RE100.[*,26] Through 2017, almost 8,880 megawatts of wind had been procured by non-utility purchasers.[27]

In addition to the increasing use of natural gas and renewable energy for electricity production, states and consumers continue to invest in energy efficiency programs, lowering household electric bills and reducing greenhouse gas emissions. In 2015, state energy efficiency programs saved more than 26 million megawatt hours, nearly double the amount saved in 2010.[28] These programs resulted in almost one percent savings in total U.S. electric demand in 2015,[29] and utilities and states continue to improve and tailor their programs to capture benefits for consumers.[30]

Figure 3.1. Historic Generation Trends of Select Fuel Types (terawatt hours)



Sources:
MJB&A Analysis.
U.S. EIA, Monthly Energy Review, Table 7.2b Electricity Net Generation: Electric Power Sector, January 2018.

* In the U.S., RE100 includes Apple, Coca-Cola, Facebook, General Motors, Google, Microsoft, Nike, Starbucks, and other leading technology and consumer goods companies. The companies are entering into direct agreements for renewable energy.

These trends suggest more changes ahead. Wind and solar technology deployment has repeatedly exceeded forecasts as a result of falling costs and federal, state, and local policy incentives.[31] There are strong indications that other technologies such as utility scale battery electric storage and electric vehicles will be deployed at increasing rates in the coming decade.[32] Other potential drivers of change include the growth in demand response and distributed energy resources, grid modernization, incorporation of dynamic pricing, increased public interest in choosing energy resources, and alternative utility structures.[33] These trends are important factors for any U.S. electric power industry scenario developed by a company, including a reference or business-as-usual outlook.

While the U.S. electric power industry is already transitioning to a lower carbon system, many of the current trends would have to be significantly amplified — in pace and scale — to reduce emissions on trajectories consistent with meeting a 2-degree target (as discussed in the text box below, some states and regions have already established interim reduction targets and are implementing policies consistent with the targets). Understanding how the potential pace and scale of change associated with a 2-degree transition would impact a business is the underlying motivation for investors' questions concerning climate risk. A scenario that explores a 2-degree transition should detail how a set of well-defined driving forces could catalyze a significant restructuring of the U.S. electric system and, more specifically, portions of the grid within the geographic scope of the analysis.

Emissions Reduction Trajectories for a 2-Degree Scenario

A key parameter for companies to identify and justify in the development of a 2-degree transition scenario is the GHG emission reduction trajectory. According to the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report, developed countries, including the U.S., will need to cut net economy-wide GHG emissions at least 80 percent below 1990 levels by 2050 for there to be a realistic chance of meeting a 2-degree target.[34] Other international, national, and subnational

Commitments to Emission Reduction Goals

In 2009, leaders of G8 countries, consistent with the science, committed to reduce emissions by 80 percent or more by 2050. While the Trump Administration has moved away from previous U.S. commitments to reduce emissions in line with this long-term target, many states and cities remain committed to these long-term goals:

- California set an 80 percent reduction target below 1990 levels by 2050 in its greenhouse gas law;
- Oregon is considering a binding target of 80 percent;
- Massachusetts, Maryland, New York, New Hampshire, Rhode Island and Vermont have set targets on pace with an 80 percent reduction;
- 398 mayors representing 69 million Americans are part of Climate Mayors, a group of mayors committed to upholding the Paris Agreement goals; and
- more than 2,500 leaders from cities, states, companies and universities, representing more than 130 million Americans and $6.2 trillion of the U.S. economy have signed the We Are Still In declaration, which is committed to delivering on the promise of the Paris Agreement.

References:

Group of 8 Summit 2009, "Chair's Summary", July 10, 2009. Available at: http://ec.europa.eu/economy_finance/publications/pages/publication15572_en.pdf.

Stern, Todd, "Letter to Mr. Yvo de Boer, Executive Secretary, United Nations Framework Convention on Climate Change from the UnitedStates Department of State Office of the Special Envoy for Climate Change on the U.S. Submission to the Copenhagen Accord", January 28, 2010. Available at: https://unfccc.int/files/meetings/cop_15/copenhagen_accord/application/pdf/unitedstatescphaccord_app.1.pdf.

United States Department of State, "United States Intended Nationally Determined Contribution Submission to the UN Framework Convention on Climate Change", March 31, 2015. Available at: http://www4.unfccc.int/ndcregistry/PublishedDocuments/United%20States%20of%20America%20First/U.S.A.%20First%20NDC%20Submission.pdf.

Governor of California Arnold Schwarzenegger, "Executive Order S-3-05", June 2005. Available at: http://www.csus.edu/indiv/s/shulockn/executive%20fellows%20pdf%20readings/executive%20order%20s-3-05.doc.

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Georgetown Climate Center, "Reduce Greenhouse Gas Emissions from Transportation: Opportunities in the Northeast and Mid-Atlantic — Technical Appendix: State GHG Reduction Goals in the TCI Region", November 2015. Available at: http://www.georgetownclimate.org/files/report/Apndx3_TCIStateEnergyClimateGoals-Nov2015-v2_1.pdf.

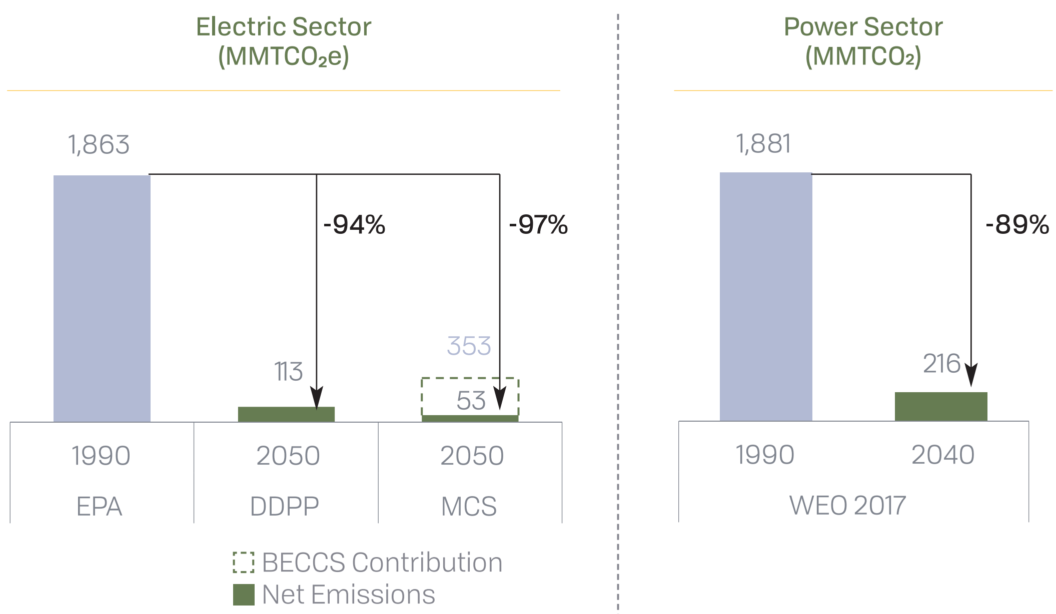
Climate Mayors, "U.S. Mayors Demonstrate Ambitious, Collective Climate Leadership", December 2017. Available at: http://climatemayors.org/

We Are Sill In, "We Are Sill In Declaration", December 2017. Available at: https://www.wearestillin.com/we-are-still-declaration.

commitments have affirmed this target. Achieving an 80 percent reduction in net economy-wide GHG emissions in the U.S. by 2050 would require sustained actions across all economic sectors. However, the rate and relative share of reductions across sectors are not proportional. As discussed in more detail in Appendix A, modeling suggests that some sectors would likely cut emissions by more than 80 percent while others would cut emissions by less. This is due to the assumed cost and technical challenges of reducing emissions from different sources. For example, opportunities in the transportation sector may lag those in the electric power sector due to slow stock turnover.

Reflecting the range and costs of emission reduction opportunities available to the U.S. electric power industry, most modeling suggests the industry would need to reduce emissions at least 90 percent from 1990 levels by 2050 for the U.S. to achieve an 80 percent reduction. As summarized in **Figure 3.2**, the federal government's modeling in support of the "U.S. Mid-Century Strategy for Deep Decarbonization" (U.S. MCS or MCS) found under a Benchmark scenario that the electric power industry would reach "near-complete decarbonization" with GHG reductions of greater than 95 percent from 1990 levels by 2050, including credit for negative emissions by capturing and sequestering carbon dioxide from biomass energy facilities. Similarly, the

Figure 3.2. 1990 Emissions and Comparisons Across Models (2040 and 2050)



Note: MCS estimate includes contribution of biomass energy with CCS (BECCS) but does not account for upstream emissions associated with biomass farming and transportation and indirect land-use impacts.

Power Sector emissions include industrial heat

Sources:

MJB&A Analysis.

EPA: U.S. EPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2015", April 2017. Available at: https://www.epa.gov/sites/production/files/2017-02/documents/2017_complete_report.pdf.

DDPP (Mixed Case): Deep Decarbonization Pathways Project, "Pathways to Deep Decarbonization", 2014. Available at: http://unsdsn.org/wp-content/uploads/2014/09/US-Deep-Decarbonization-Report.pdf.

MCS (Benchmark): The White House, United States Government, "United States Mid-Century Strategy for Deep Decarbonization Documentation and Output Data", November 2016. Available at: http://unfccc.int/files/focus/long-term_strategies/application/pdf/us_mcs_documentation_and_output.pdf.

WEO 2017 (Sustainable Development Scenario): International Energy Agency, "World Energy Outlook 2017", November 14, 2017. Available at: https://www.iea.org/weo2017/.

International Energy Agency (IEA) World Energy Outlook 2017 Sustainable Development Scenario (WEO 2017) found that emissions in the U.S. power industry would have to decline almost 90 percent from 1990 levels by 2040.* Across four 2-degree transition scenarios in a report published by the Deep Decarbonization Pathways Project (DDPP),† emissions associated with electricity were modeled to decline between 80 and 94 percent. A "Mixed Case" intended to incorporate a more diverse mix of technologies resulted in the largest electric power industry emission reductions. These modeling efforts are reviewed in more detail in Appendix A.

Achieving at least a 90 percent emissions reduction across the U.S. electric power industry would entail some companies and regions *exceeding* 90 percent reductions, while others would not reach that level. When developing scenarios that reflect the ambition associated with meeting a 2-degree target, companies should consider what unique economic, political, and technological factors would influence their emission reduction trajectory and justify their conclusion. Interim emission reductions (e.g., by 2030 or 2040) could be established using existing state targets or other reasonable assumptions about the expected rate of reductions. However, it is important for a company to recognize and evaluate the pace and scale necessary to transition electric power industry infrastructure to meet 2050 reduction targets along a plausible transition pathway.

Constructing a 2-Degree Scenario

Each company will have to make decisions about how it incorporates existing 2-degree modeling along with other resources such as projections for technology development into its own scenario or scenarios. In some areas, there may be state agencies or research institutions that have developed existing scenarios that are appropriate for a company to apply. To gain a deeper level of insight, a company may want to develop its own scenarios and use the outside resources as a check against assumptions. Developing company-specific scenarios is a significant undertaking but can also provide important insights through the process of developing and then applying the scenario.

To develop one or more customized scenarios, a company would plan and implement a scenario development process as outlined in Section 2. As part of the process, the company would identify driving forces. The driving forces are important factors that are currently shaping or have the potential to significantly influence future conditions in the U.S. electric power industry. Examples of driving forces to consider as part of a 2-degree scenario include:

- The rate of GHG emission reductions, including assumptions about potential reductions in other economic sectors;
- The extent to which various energy end-uses, such as heating and transportation, are electrified;
- The role for energy efficiency in reducing GHG emissions;
- The overall impact of a 2-degree transition on energy demand;
- The future costs of clean energy technologies;
- The impact of climate and clean energy policies on investments in specific clean energy investments, the costs and efficiency of different policy approaches, and the scope and level of consistency of policies across jurisdictions;
- The influence of consumer preferences and corporate procurement on demand for clean energy and specific types of resources;
- The pace of deployment of energy technologies, including carbon capture and sequestration (CCS), nuclear, solar, wind, and battery storage; and
- The impact of technological change and distributed electricity on electric power industry regulatory and market structures.

These driving forces along with other potential factors can be closely examined during the scenario development process. A company can consider the degree of uncertainty for each driving force and the potential impact it could have on future business conditions. This assessment enables the company to identify critical uncertainties to examine through scenarios. Working through the scenario development process, the company can develop one or more scenario narratives that describes how specific driving forces could progress over time, aligning motivations and strengthening market signals for investments in technologies that significantly displace carbon-intensive infrastructure.

* WEO does not separate out electricity emissions from total power sector emissions. Power sector emissions also include industrial power.

† The DDPP is a joint project of Energy + Environmental Economics, Lawrence Berkeley National Laboratory, and Pacific Northwest National Laboratory. The DDPP modeled four scenarios including: High Renewables Case, High Nuclear Case, High CCS Case, and Mixed Case. The Mixed Case is the main case in the DDPP report, intended to incorporate a greater mix of technologies for illustrative purposes. The Mixed Case is reflected in Figure 2 and throughout the report.

Electric Power Industry Scenarios — A Case Study on National Grid U.K.'s Future Energy Scenarios

Every year since 2011, National Grid has published its "Future Energy Scenarios," a set of energy scenarios for the United Kingdom (U.K.) that model credible future energy landscapes. The scenarios provide information to U.K. policymakers, energy-sector companies and National Grid U.K. stakeholders as they make decisions about potential risks and opportunities associated with future outcomes. National Grid's scenarios represent the type of modeling effort that U.S. companies could undertake when developing 2-degree scenarios.

National Grid's scenarios and accompanying report are similar to the U.S. Energy Information Administration's Annual Energy Outlook, except that instead of attempting to forecast future conditions based on current policies and technology improvements, National Grid models a range of potential outcomes for the U.K.'s energy system under uncertain conditions. In previous years, National Grid produced a "Gone Green," "Super Green," and "No Progress" scenario, among other scenarios. Its 2017 report updated the scenarios to "Two Degrees," "Slow Progression," "Consumer Power," and "Steady State" scenarios.

The Two Degrees scenario shows a cost-optimal pathway to meeting the U.K.'s target of reducing GHG emissions 80 percent from 1990 levels by 2050. The Slow Progress scenario has lower economic growth and high energy prices, which delay achievement of emissions reduction targets despite strong ambition on environmental issues. On the other hand, the Steady State and Consumer Power scenarios achieve less ambitious climate goals as the 2050 targets are not regarded as critical in the thinking of policy makers or consumers.

The report provides a comprehensive breakdown of different factors within the gas and electricity sectors across these scenarios, including future energy demand, generating capacity and supply, market penetration of demand response and electric vehicles, and natural gas supply. The report also explores sensitivities around distributed generation, end-use electrification, including electric vehicle penetration, and availability of carbon-free gas.

A benefit of the report is the transparency with which National Grid reports its modeling assumptions and outputs. A key of all climate-related assessments is transparency, and when undertaking their own analyses, companies should strive to a similar level of transparency.

Reference:

National Grid, "Future Energy Scenarios", July 13, 2017. Available at: https://www.nationalgrid.com/uk/publications/future-energy-scenarios-fes.

Once established, the qualitative scenario narratives can be used to develop forward-looking market assessments. Quantifying various scenario pathways can provide even greater insight into the market implications of the scenarios. At the same time, the process of quantifying and assessing the potential market impacts allows a company to further test the key assumptions incorporated into the scenario narratives. Development of the qualitative and quantitative components of a scenario can be an iterative process where scenario assumptions are adjusted based on feedback and insights gained from economic modeling.

Whatever approach a company uses to incorporate a 2-degree transition into scenarios, it is important to articulate and report out the assumptions for each specific pathway and explain or justify why each assumption is plausible. This includes macroeconomic assumptions in demographics and economic growth that can significantly influence model results. Laying out the assumptions is critical to engaging internal stakeholders within a company and engaging with external stakeholders when reporting key insights and findings.

4. KEY CONSIDERATIONS FOR INCORPORATING PHYSICAL IMPACTS INTO A SCENARIO

As the U.S. electric power industry is transitioning to a lower carbon system, the physical impacts due to a changing climate are also increasingly apparent and affecting the industry. These impacts are projected to grow more intense and costly in the coming decades. As a result of climate change, the U.S. is experiencing and is projected to continue to experience increased temperatures, lengthened frost-free seasons, altered annual and seasonal precipitation patterns, greater instances of heavy downpour events, rising sea levels, and more intense extreme weather events, including drought, heat waves, hurricanes, wildfires, and other weather events.[35] The National Oceanic and Atmospheric Administration (NOAA) estimates that the U.S. experienced 16 distinct billion-dollar weather disasters in 2017, including hurricanes, wildfires, hail storms, tornados, and heavy precipitation events — totaling a record $300 billion in damages.[36] In 2018, the World Economic Forum's "Global Risks Report" ranked climate-related impacts at the top of its list of risks that will affect the global community.[37]

The electric power industry is exposed to climate risks due to its dependence on a large, capital-intensive, and distributed infrastructure and society's dependence on reliable service. Physical climate impacts can be both acute and chronic. Acute impacts are the result of discrete events such as a heavy downpour events, while chronic impacts are changes to underlying conditions, such as sea level rise.*

Companies, investors, consumers, and other key stakeholders are interested in the financial and business-related risks of climate change. By incorporating potential physical impacts of climate change into scenarios as part of a climate strategy assessment, companies can enhance their knowledge to inform strategic decisions while also responding to stakeholder interest. Key elements of an assessment include how a range of potential impacts may affect specific assets, overall operations, and market conditions:

- Temperature and extreme heat;
- Water availability and precipitation patterns;
- Sea level rise;
- Extreme precipitation events, hurricanes, tropical storms, and coastal storm surge;
- Wildfires; and
- Changes in wind patterns.

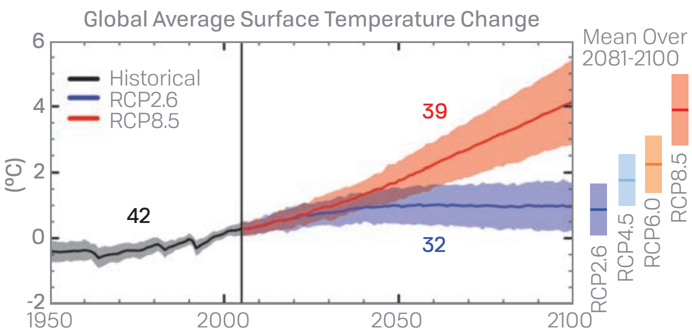
Rather than relying on past trends to anticipate future conditions, companies can use scenarios to assess potential physical conditions in the future and consider how these conditions could affect existing infrastructure and new capital investments.[38] Scenario planning provides a powerful tool to integrate these considerations with many other changes affecting the future business landscape.[39] Scenarios that incorporate low-carbon transition characteristics with the physical effects of a changing climate enable companies to consider optimal pathways to a resilient and low-carbon electric system.

When considering how to account for physical impacts of climate change, companies should assess a range of potential future conditions. According to the IPCC, it is virtually certain that global temperatures will continue to rise through the end of the century and reach at least 2 degrees warming by 2100.[40] The magnitude of climate impacts does not increase linearly as temperatures rise. Certain trajectories could trigger tipping point events and feedbacks where certain climate conditions cause drastic changes that accelerate increases in physical risks. For instance, melting of permafrost due to climate change could rapidly release carbon dioxide and methane that was previously sequestered, accelerating and exacerbating climate change. This underscores the need for companies to prepare and adapt to potential impacts across a range of temperature outcomes. To account for this variation, companies may consider evaluating scenarios where

* For the purpose of this section, a climate change "impact" is a physical manifestation of climate change resulting in a change in conditions, such as increased temperature or more extreme storms. A climate "risk" is the resultant effect this climate change impact could have on energy sector company operations, such as increased stress to grid infrastructure.

temperatures stabilize at higher levels, including those ranging from 3 to 5 degrees above preindustrial levels (see **Figure 4.1** for a range of projections developed by the IPCC).

Figure 4.1: IPCC Temperature Projections under Emissions Scenarios



Source:

Figure SPM.7 (a) from IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker,T.F., D.Qin, G.-K. Plattner, M.Tignor, S.K.Allen, J.Boschung, A.Nauels, Y.Xia, V.Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK and New York, USA.

Over the past several years, significant progress has been made developing tools that provide more granular information on local impacts to help communities and industry plan for climate change. Appendix B reviews the expanding suite of existing tools, reports and data. A key resource is the U.S. National Climate Assessment (NCA), a comprehensive, multiagency report published by the U.S. Global Change Research Program (USGCRP) detailing the impacts of climate change on the U.S. The 3rd NCA, which was published in 2014, includes supplemental chapters and materials, including a chapter dedicated to the energy sector, and regional summaries. In November 2017, the U.S. government released the first volume of the 4th NCA which reflects the latest science on climate change. A second volume, scheduled to be released in mid-2018, will provide more detailed information on the projected impacts of climate change to regions and sectors.

In addition to the NCA, DOE's 2013 report "U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather," provides a comprehensive breakdown of the risks associated with the primary impacts of climate change. In 2015, DOE launched its "Partnership for Energy Sector Climate Resilience," a partnership comprised of 19 electric and gas utility companies, including investor-owned, federal, state and municipal and cooperative utilities. This effort has started a public process to share best practices for and results from vulnerability assessments — analyses of possible sector impacts due to climate change — that companies can use to explore ways to incorporate physical risks into climate-related assessments. Under the partnership, companies agreed to "develop and pursue strategies to reduce climate and weather-related vulnerabilities"[41] where the companies identified climate stressors, performed a vulnerability assessment and developed a set of resilience solutions.[42] Through the end of 2017, 17 companies had conducted an assessment.[43] Some assessed vulnerabilities quantitatively across the full range of assets and physical impacts while others only looked at a subset of assets and impacts over a limited period of time. While these companies are among those leading the electric power industry in assessing climate risk, few have released their reports publicly as stand-alone climate vulnerability assessment reports. Seattle City and Light is one of the companies that took a comprehensive approach to its climate vulnerability assessment and released its findings publicly **(see text box on the following page)**.[44]

DOE has also released a step-wise guide for conducting vulnerability assessments.[45] In addition to this effort, California, New York City, and Boston have developed state and sector climate vulnerability assessment guides.[46,47,48] These reports can also serve as resources for assessments.

Appendix B reviews many of the tools available to companies as they work to understand the potential impacts of climate change to their business. Each company will need to determine the impacts that are most relevant given its geographic footprint and its assets. The identified impacts can be incorporated into a range of scenarios to assist companies. Companies may also choose to look at separate physical impact-focused scenarios to further prepare for the potential impacts of climate change. However, there are benefits to incorporating climate impacts into broader scenarios to better understand the interplay between different driving forces and potential impacts.

As with other elements of scenarios, it is important for companies to provide clear and transparent information about the scenarios including references to the tools used to understand the potential impacts and assumptions about the degree of potential change.

Assessing Climate Impacts — A Case Study on Seattle City Light

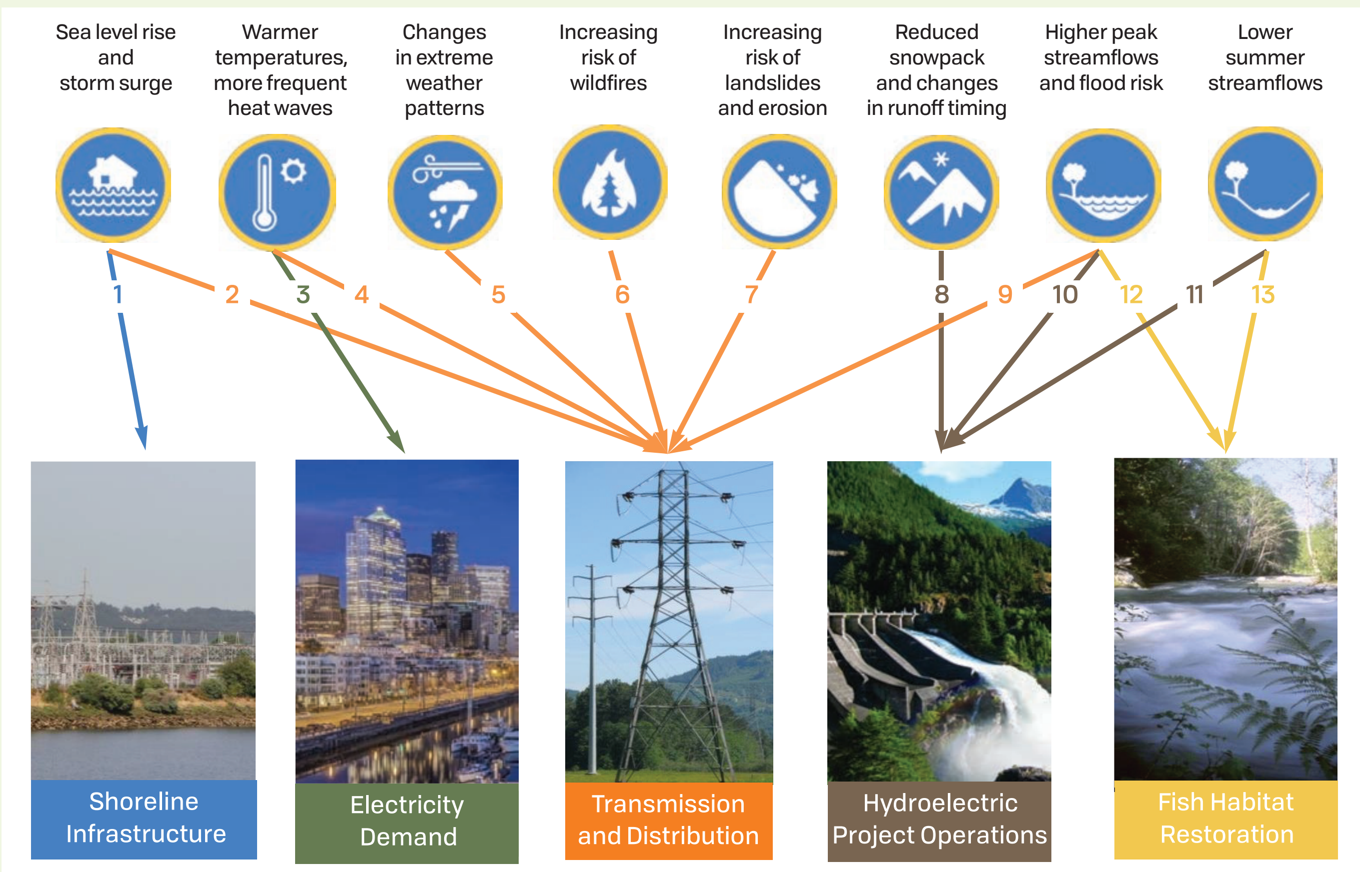
Seattle City Light is a participant of DOE's Partnership for Energy Sector Climate Resilience and in 2015, the publicly owned electric power utility conducted and released its "Climate Change Vulnerability Assessment and Adaptation Plan." The report is a leading example of a comprehensive and detailed analysis that informs both company decision-makers and external stakeholders.

The report is thorough, detailed and action-oriented and reflects the latest science in assessing the impact of sea level rise, temperature increases, extreme weather events, snowpack, wildfires, and other changes in climate on each of the utility's assets and business aspects. These assets include the business' coastal infrastructure, electricity demand, transmission, hydroelectric facilities, and fish and wildlife habitat land. Seattle City Light's report assesses its vulnerability for each impact based on three factors (its exposure to these impacts, its sensitivity to these impacts, and its capacity to adapt by 2030 and 2050) and helpfully presents data both qualitatively in text but also clearly and concisely in tables. Seattle City Light includes discussion of impacts to finances, employee safety, and reliability, which are important details for investors, ratepayers, and other stakeholders. As summarized in the graphic below, Seattle City Light identifies thirteen impact pathways through which the utility could experience climate-related risks.

Finally, the company identifies the potential near-term and long-term actions it could take for each business aspect and impact to reduce its vulnerability and is convening an interdisciplinary team to implement the actions identified in the report. Seattle City Light has committed to updating the report in 2018, integrating the latest data and reflecting the latest actions to date.

Climate Change Vulnerability Assessment

This vulnerability assessment describes eight changes in the climate, and resulting changes in natural hazards and streamflow that could affect five aspects of City Light's operations and infrastructure. Together they create thirteen impact pathways through which the utility could experience climate-related risks to its mission.



Reference:

Raymond, Crystal, "Seattle City Light Climate Change Vulnerability Assessment and Adaptation Plan", Seattle City Light, 2015. Available at: http://www.seattle.gov/light/enviro/docs/Seattle_City_Light_Climate_Change_Vulnerability_Assessment_and_Adaptation_Plan.pdf.

5. APPLYING SCENARIO ANALYSES FOR CLIMATE STRATEGY ASSESSMENTS

Scenarios are a critical component of a climate strategy assessment, but like any planning process, the value of the exercise will be defined by how a company integrates insights from scenarios into its planning and strategy. Scenario planning can help a company push the bounds of conventional wisdom and explore credible and plausible outcomes that may have previously been overlooked. However, the extraction of key insights and application of those insights to the business are equally important.

Assessing the implications of a 2-degree transition and the physical impacts of climate change through scenario planning strengthens a company's assessment of future risks and opportunities for the business, preparing a company to adapt and prosper in an uncertain future. Rigorous assessments ensure that a company is fulfilling its obligations to customers and shareholders, as well as other investors and external stakeholders. Accordingly, businesses can use scenarios to identify vulnerabilities and opportunities affecting their bottom-line or impacting the quality of service. For instance:

- How quickly and to what degree could the utilization of existing fossil fuel-fired power plants change under a 2-degree transition?
- How sustainable are existing revenue models (regulatory and market-based) under scenarios with greater penetration of renewables and distributed energy resources?
- What are the vulnerabilities and challenges for specific assets and overall operations due to the physical impacts of climate change?
- How would a 2-degree transition affect asset valuation, capital requirements, revenue, and costs?

Climate-related assessments provide an opportunity to open an internal dialogue and begin to understand the scale and scope of what would need to occur within the business under a range of future states. They can be used to help businesses assess how various projections conflict or harmonize with current strategies as well as customer expectations around clean energy supply, cost, and reliability. Finally, a comprehensive scenario analysis can help address investors' questions about the long-term viability of a business.

2-Degree Transition Scenarios and Corporate Planning

Many companies already use scenario analysis to support business planning. Some have already begun to develop 2-degree transition scenarios. In recent years, a number of oil and gas companies, including BP, Chevron, ConocoPhillips, ExxonMobil, Statoil, and Total have started to integrate 2-degree analyses into strategic analysis and public reporting.* In the metals and mining sector, BHP Billiton and Glencore have modeled and reported on how a range of future scenarios, including a 2-degree transition would affect operations.†

Rigorous assessments ensure that a company is fulfilling its obligations to customers and shareholders, as well as other investors and external stakeholders.

* Chevron, Total, ConocoPhillips, and Statoil relied on IEA's 450 Scenario for their analyses. BP and Shell used their own internal scenario analysis to model 2-degree scenarios. ExxonMobil incorporated analysis published by the Stanford University Energy Modeling Forum.

† BHP Billiton developed its own models including a "Global Accord" model that assumes the world acts to limit climate change to 2 degrees warming. Glencore based its analysis on IEA's 450 scenario.

2-Degree Scenario Analysis in the Electric Power Industry — A Case Study on SSE

In 2017, SSE, a U.K.-based energy company, released a report that assesses the impact of various transition scenarios, including a 2-degree scenario, on the business. The company developed a 2-degree scenario analysis at the request of its investors with the goal of stress testing its business against ambitious transition scenarios and determining the business' resilience to these future states of the world. The resulting report, titled "Post-Paris: Understanding SSE's long term resilience against different carbon reduction scenarios following the Paris Agreement," was one of the first electric power industry climate strategy assessments and includes detailed modeling, and quantitative and qualitative analysis.

As the foundation for its modeling analysis, SSE uses National Grid U.K.'s 2016 Future Energy Scenarios **(see National Grid text box on page 16)** and examines a scenario that looked at the possibility of a more limited role of nuclear generation starting in 2030, as well as a "Super Green" 1.5-degree scenario, which SSE indicates "will be an extremely challenging target to meet". After introducing the scenarios, SSE's report walks readers through its current generation mix and planned projects through 2030. It identifies some central weaknesses and strengths of the business that would manifest in each of the modeled scenarios. In terms of emissions, it compares SSE's current emissions with those corresponding to Great Britain-wide reductions envisioned in the 2-degree "Gone Green" scenario. While SSE would need to dramatically reduce its emissions, SSE notes that it is confident that, through the scale-up of renewable generation, it could meet the target. In out years (particularly after 2030), the report contains fewer specifics, citing lower confidence in future pathways.

The company's discussion of strengths, opportunities, weaknesses and threats associated with the various scenarios is helpful and can be used by the company to assist in identifying critical next steps to make the business more resilient. For example, SSE identified the following strengths and opportunities resulting in a 2-degree scenario:

- Increased electricity demand from the electrification of end-uses;
- Potential adoption of policy frameworks that send the proper signals to the electricity market; and
- Market opportunities due to SSE's investment in renewable energy, renewable energy transmission, and resources that promote system flexibility.

Among its threats, SSE considers the impact of distributed generation on the traditional grid infrastructure and the risks and trade-offs of investing in natural gas and renewables under 2-degree and other scenarios.

Reference:

SSE, "Post Paris: Understanding SSE's long term resilience against different carbon reduction scenarios following the Paris Agreement", July 2017. Available at: http://sse.com/media/473275/Post-Paris_FINAL_06072017.pdf.

As discussed in more detail in the **text box**, SSE, a U.K.-based energy company released a report that includes a scenario with a 2-degree transition. While there are opportunities for SSE to expand on its discussion of what a 2-degree transition would mean to the business (e.g., by stating whether it would be able to achieve the GHG targets under the most aggressive scenario), it provides an example of the use of a scenario by a company that has electric power assets to better understand the implications of a 2-degree transition. Outside of energy sector, investors such as CalSTRS and the New York State Common Retirement Fund have used scenarios to analyze the impact of 2-degree transitions on their investment portfolios.

Companies may find in the process of conducting a 2-degree scenario analysis that they identify opportunities for their business based on the feasibility of a 2-degree transition and the benefits derived from low carbon and more sustainable operations. For example, Statoil was one of the first oil and gas companies to analyze the implications of a low-carbon transition to its business. As a result of that analysis, Statoil divested from high carbon assets including the oil sands; made clean energy one of the three pillars on which its business is built, and earlier this year set a goal of spending 15 to 20 percent of capital on clean energy within a decade, up from five percent today. In a recent analysis the company concluded that the changes it has made in its portfolio mean that the company's value would actually rise in a two-degree transition.[49]

Austin Energy, a publicly owned utility providing electrical power to the city of Austin, Texas, provides a useful example. In 2014, the Austin City Council passed a resolution pledging to reach a community-wide goal of net zero emissions by 2050.[50] Austin Energy has committed to reducing its emissions consistent with this community-wide goal and worked with a City of Austin Electric Utility Commission-led Task Force to model various pathways of how it could achieve deep decarbonization. As a result of this experience, Austin Energy identified more cost-effective pathways to reduce emissions through scaling renewable energy, phasing-out existing fossil plants, and achieving energy efficiency and demand response targets.[51]

More recently PPL and American Electric Power (AEP) announced carbon dioxide emission reduction goals. In January 2018, PPL announced plans to cut the company's carbon dioxide emissions 70 percent from 2010 levels by 2050.[52] This announcement followed the December 2017 release of PPL's corporate climate assessment. In announcing the reduction target, PPL noted: "Based on that assessment, we believe the goal we have set is both achievable and in the best interests of PPL's customers and shareowners as we look to grow value moving forward." In February 2018, AEP announced new goals in response to ongoing engagement with stakeholders. AEP's goals are to reduce carbon dioxide emissions from generating facilities by 60 percent from 2000 levels by 2030 and by 80 percent from 2000 levels by 2050.[53] AEP also highlighted the company's anticipated new power plant capacity (wind, solar, and natural gas) to 2030.

Physical Impacts and Corporate Planning

Companies in the electric power industry have also used scenario analyses to examine the potential physical impacts of climate change and have applied these analyses to their business. As discussed in Section 4, DOE's Partnership for Energy Sector Climate Resilience has worked with companies to develop vulnerability assessments of energy infrastructure assets. DOE notes that these analyses can be used to estimate the probability and consequences of impacts on assets and develop resilience measures. Resilience measures could either reduce the probability of damage and disruption caused by a climate impact or reduce the consequences of a disruption depending on their approach to risk.[54] For instance, companies in the electric power industry may wish to reduce the likelihood of a risk, transfer the risk on to other entities, shift operations to avoid exposure to a risk, or accept a risk.[55]

Resilience measures could either reduce the probability of damage and disruption caused by a climate impact or reduce the consequences of a disruption depending on their approach to risk. For instance, companies in the electric power industry may wish to reduce the likelihood of a risk, transfer the risk on to other entities, shift operations to avoid exposure to a risk, or accept a risk.

Physical impact assessments can be used for near-term planning as well as long-term risk assessment and planning. Near-term planning helps companies prepare and respond to immediate risks posed by climate change and may include approaches such as hardening specific assets. Long-term risk assessment helps companies develop foundational changes that will make systems more resilient in the longer planning horizon. This may include developing a grid that is more flexible and responsive to a range of climate impacts.[56]

Available tools and information to assess the physical impacts of climate change are expanding quickly. At the same time, leading companies are enhancing their capabilities to better process this information into actionable insights. The text box on the following page describes a detailed modeling exercise that Pacific Gas and Electric Company conducted to assess climate impacts on company-wide risks. Leveraging new tools and information, the comprehensiveness and scope of the assessments should continue to improve as companies gain experience in accounting for climate impacts.

Assessing Climate Impacts — A Case Study on PG&E's Risk Assessment Mitigation Phase Report

On November 30, 2017, Pacific Gas and Electric Company (PG&E) submitted its 2017 Risk Assessment Mitigation Phase (RAMP) Report, which includes a detailed modeling exercise regarding climate impacts on company-wide risks. The RAMP Report, a new requirement for large California energy utilities, stems from a California Public Utilities Commission risk-based decision-making framework. Consistent with these and other requirements, PG&E's RAMP Report includes initial quantitative, probabilistic views of the company's top safety risks; identifies the costs associated with current activities and controls associated with these risks; and describes future mitigation plans based on alternatives analysis and informed by the concept of risk-spend efficiency.

In its report, PG&E conducts a modeling exercise to better understand the current and future impacts of climate change and how those impacts could serve as a multiplier and increase other identified PG&E risks. PG&E's Climate Resilience RAMP model explores six risk drivers: (1) rising sea levels; (2) major storm event days; (3) increasing temperatures and heatwaves; (4) wildfires; (5) drought; and (6) land subsidence. Each one of these drivers is considered to be a sub-driver of other risks; in other words, the consequences of climate change are considered in the context of how much worse climate change could make PG&E's other risks. These include risks to overhead conductors, natural gas infrastructure, and the hydropower system. For example, stronger and more frequent storms could lead to additional risk to PG&E's distribution overhead conductors, as more wires may be downed as a result.

PG&E aims to use the output of this assessment in a structured manner to conduct foundational work to propose actions to reduce climate risk. It notes that this analysis is necessary as "it is increasingly challenging to rely on historical data to determine what to expect and plan for in terms of a '100-year storm event' or 'number of heatwaves per summer.'" This work will serve as an input to PG&E's efforts to design a company-wide climate change risk integration strategy. This strategy will inform resource planning and investment and operational decisions, and result in the potential for additional programs to identify and pursue mitigations that will make PG&E's assets, infrastructure, operations, employees, and customers more resilient to climate change to reduce safety consequences.

Reference:

Pacific Gas and Electric, "PG&E's 2017 Risk Assessment and Mitigation Phase Report", December 2017. Available at: http://docketpublic.energy.ca.gov/PublicDocuments/17-IEPR-09/TN221908_20171205T160625_PGE_RAMP_Report.pdf.

Evaluating Resilient, Low-carbon Strategies

While some businesses have conducted 2-degree transition analyses and others have looked at the physical impacts of climate change, few have integrated the two. Assessing the physical and transition-related implications in an integrated approach can help to more fully characterize the potential changes facing the electric power industry. It is likely that certain physical and transition factors have synergies that compound the business impact or counteract each other. For instance, companies may face a future where they have increased demand for electricity due to electrification of end-uses while they are also experiencing greater demand due to extreme heat and decreased capacity due to generation inefficiencies. Exposure to sea level rise and extreme storms coupled with the prospect of devalued fossil-fuel assets due to potential climate policy may influence a company's decision about the future of an asset. For these reasons, the assessment of potential physical impacts should be integrated into broader scenarios including 2-degree scenarios.

Integrating 2-degree transition analyses with the physical impacts of climate change will enable a more comprehensive assessment of the business landscape and support more informed decisions about future risks and opportunities. Climate strategy assessments can help businesses begin to identify actions that they can take to make the business more resilient to potential disruptions posed by climate change and at the same time respond to opportunities presented by 2-degree transitions. Businesses may also uncover inevitable or near-inevitable future conditions.[57] A company's ability to identify predetermined elements might present no-regrets opportunities that allow businesses to benefit even in uncertainty about the full scope of future conditions.

Table 5.1 on the following page provides a more extensive list of risks and opportunities associated with a 2-degree transition and physical impacts of climate change for consideration as part of a climate-related assessment. This list is not comprehensive, and businesses will likely identify additional risks and opportunities through their internal process of conducting an assessment. Initially, it may be easiest for companies to evaluate these challenges on an asset by asset basis. However, this approach is likely to miss the broader and potentially larger implications. A more comprehensive approach that looks at the implications of these factors across the interconnected electric grid enables a more robust

Table 5.1. Examples of Potential Business Risks and Opportunities

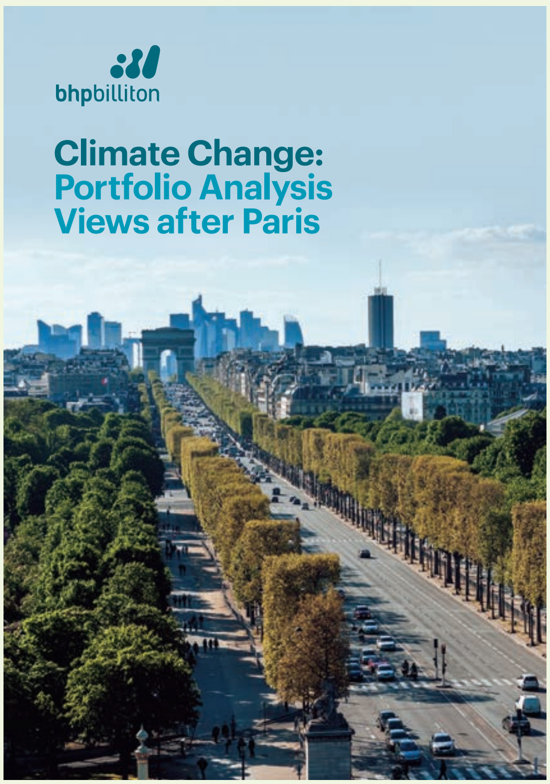
INDUSTRY SEGMENT	RISKS	OPPORTUNITIES
Overarching	· Reputation risk from carbon-intensive portfolios · Higher insurance premiums, reduced access to capital due to discrete and recurring costs from extreme weather events or chronic climate impacts · Increased shareholder concern and divestment · Exposure to costs associated with complying with federal, state and local policies	· Market opportunities for innovation achieved through R&D · Growth through electrification and delivering low-carbon energy services · Opportunities for improving efficiencies and reliability and lowering overall costs by investing in more resilient, smart grid, and low carbon technologies · Reputational benefits associated with clean energy leadership
Power Generation	· Forced early-retirement, stranded assets, loss of value of existing generation resources · Reduced revenue streams from changing supply and demand profiles · Increased discrete and recurring costs from extreme weather events or chronic climate impacts · Insufficient incentives from competitive market structures for new, low-carbon investments	· Increased demand for new, low-carbon generation · Business opportunities supplying resources with specific attributes (e.g., flexibility) that will be valued in markets with changing supply and demand profiles · Business opportunities delivering renewables and low-carbon generation to customers (e.g., commercial and industrial customers, community-based buyers) · Diversification of assets
Transmission	· Power plant retirements and changes in supply and demand profiles could reduce value of existing assets · Costs associated with hardening the electric grid to physical impacts, which may include moving assets to less vulnerable locations or making transmission and distribution resilient · Increased discrete and recurring costs from extreme weather events or chronic climate impacts	· Demand for new transmission assets to connect renewable resources with demand centers · New business models that create additional value for transmission assets
Distribution Utilities	· Effectively managing local grid (i.e., maintaining safety, affordability, and reliability) in face of increasing availability of distributed energy resources and customer demands · Insufficient revenue models to accommodate greater penetration of distributed energy resources and energy efficiency · Costs associated with hardening grid to physical impacts, which may include moving assets to less vulnerable locations or making transmission resilient to wildfires · Increased discrete and recurring costs from extreme weather events or chronic climate impacts	· New demand associated with electrification of end-uses (e.g., electric vehicles or industrial electrification) or associated with increased demand for air conditioning · Greater value for distribution assets due to expanding scope of electrification · Reduced costs to consumers through efficiency gains · Greater efficiencies through load shifting · Improved reliability through investments in smart and resilient grid technologies (e.g., benefits of energy storage technologies such as battery storage) · Improved consumer reputation benefits for clean and resilient grids

assessment of a company's overall operations and entire enterprise. Assets outside of the electric power industry, such as natural gas pipelines, can also be integrated into these analyses.

Monitoring and Reassessment

Climate strategy assessments are most valuable when they extend beyond a one-time exercise. The insights gained through scenario analysis can be applied to assess the changing business landscape on an ongoing basis. Driving forces and overall business conditions can change quickly and businesses should be prepared to respond. As part of a company's scenario and corporate planning process, climate strategy assessments offer a structured framework for monitoring the changing landscape and reassessing company strategy. Through the process of conducting an assessment, companies are positioned to identify key indicators that help illuminate emerging trends or critical milestones that may foretell bigger changes ahead. Systematic monitoring of these indicators can help detect certain tipping points that warrant close examination and potential strategy adjustments. The following text box describes how BHP Billiton monitors the external landscape to inform its strategic planning processes.

Monitoring and Reassessing — A Case Study on BHP Billiton



BHP Billiton's climate strategy assessments provide a leading example of how a business can monitor and re-assess their evaluations over time. In 2015, BHP Billiton released its "Climate Change: Portfolio Analysis," which modeled a central case and four additional scenarios looking at "plausible and divergent outcomes" in future states of the world, including Central Case and a 2-degree scenario (titled "Global Accord"). In its report, the company assessed the impacts of a 2-degree transition scenario, its resilience to 2-degree outcomes, and highlighted actions the company is taking in anticipation of climate change and climate transitions. Notably, however, the 2015 assessment was published before the December 2015 international climate negotiations and did not take into account how the global adoption of Paris Agreement would impact the business.

In response, BHP published a follow-up report in 2016 that included a new analysis that factored in the Paris Agreement. BHP's report, titled, "Climate Change: Portfolio Analysis Views after Paris," took into consideration Paris climate commitments and global mitigation momentum as well as clean energy technology advancements and cost reductions. For instance, the company's updated Central Case assumptions altered its wind, solar and electric vehicle projections.

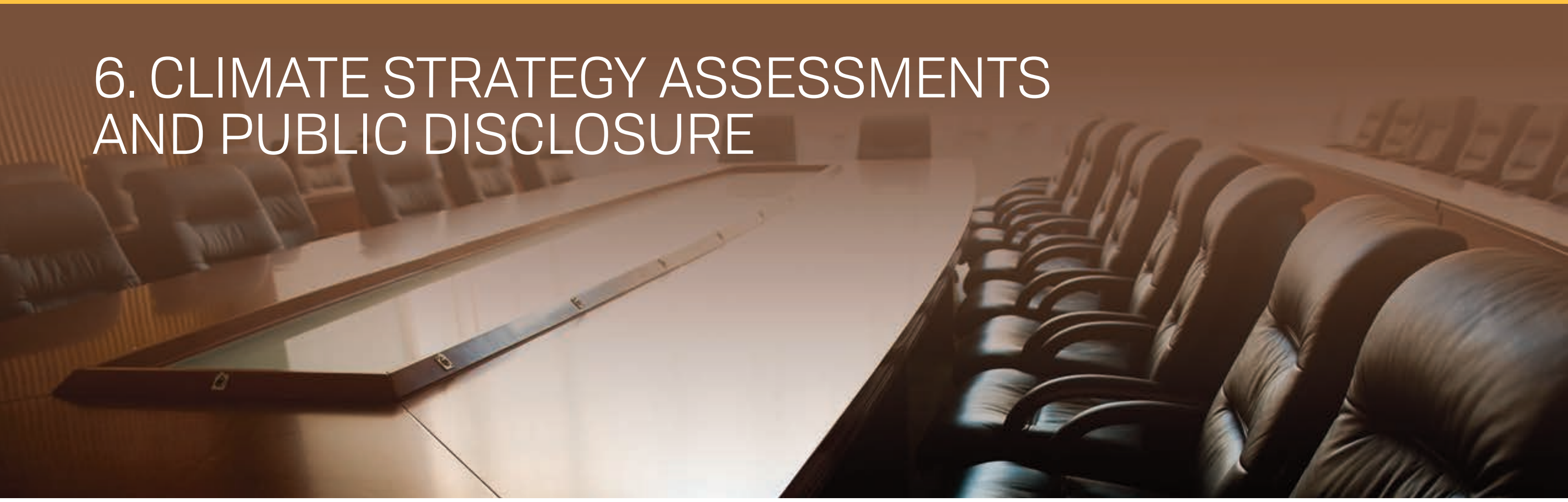
The company notes that tracking trends and new developments are central components to its strategic planning processes and cites this as a reason for why the company chose to update and release its revised scenario analysis. In conducting the reevaluation, BHP Billion ensures that the company and its investors are knowledgeable of how shifting macroeconomic trends will affect the business and ensures that the business is prepared to respond to potential future events.

Reference:

BHP Billiton, "Climate Change: Portfolio Analysis", 2015. Available at: https://www.bhp.com/-/media/bhp/documents/investors/reports/2015/bhpbillitonclimatechangeporfolioanalysis2015.pdf.

BHP Billiton, "Climate Change: Portfolio Analysis Views after Paris", 2016. Available at: https://www.bhp.com/-/media/bhp/documents/investors/reports/2016/bhpbillitonclimatechangeporfolioanalysis2016.pdf.

6. CLIMATE STRATEGY ASSESSMENTS AND PUBLIC DISCLOSURE



Investors and other stakeholders are interested in a full accounting of how companies are managing the risks and opportunities associated with climate change. In its recommendations, TCFD identified four categories of information for disclosures: governance, strategy, risk management, and metrics and targets **(see Figure 6.1)**. These topics provide important windows into how companies are actively managing the challenges associated with climate change.

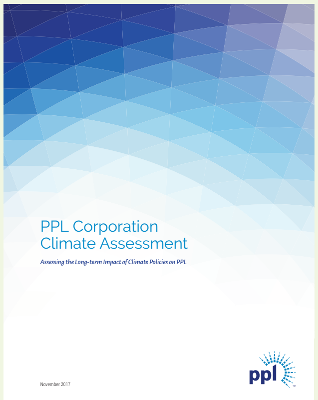
The guidance described in this document includes information identified under two of the four TCFD categories: strategy and risk management. This guidance can help inform a range of public disclosures by companies in the U.S. electric power industry, including voluntary climate reports and financial disclosures. Many companies already report climate data to CDP or through other corporate reporting and may consider expanding annual reporting to include climate-related assessments. The **text box** on the following page summarizes a climate assessment by PPL, one of the first examples of a climate assessment published by a U.S. electric company.

Investors and other stakeholders are interested in a full accounting of how companies are managing the risks and opportunities associated with climate change.

Figure 6.1. TCFD Core Elements of Recommended Climate-Related Financial Disclosure

Governance	Strategy	Risk Management	Metrics and Targets
Disclose the organization's governance around climate-related risks and opportunities	Disclose the actual and potential impacts of climate-related risks and opportunities on the organization's businesses, strategy, and financial planning where such information is material.	Disclose how the organization identifies, assesses, and manages climate-related risks.	Disclose the metrics and targets used to assess and manage relevant climate-related risks and opportunities where such information is material.

The First Published 2-Degree Scenario Analysis for the U.S. Electric Power Industry — A Case Study on PPL



In response to a shareholder resolution that received 57 percent support, PPL released a climate assessment report in December 2017, becoming the first U.S. electric utility to publicly release an assessment of the long-term impacts of reducing GHG emissions consistent with a 2-degree trajectory. PPL's report discusses the risks and opportunities associated with climate change and a low-carbon energy transition; models three scenarios; highlights action the company is taking; and summarizes the conclusions of its analysis. PPL's report opened a discussion about how a 2-degree transition may impact its generation mix, including its existing coal fleet.

While PPL's report is an important step for the U.S. electric power industry, it could benefit from further refinement, including taking into consideration some of the key elements identified in this report. For example, PPL provides limited information on how it applied the International Energy Agency's 450 scenario to the U.S. electric power industry or to its own operations, including IEA's and PPL's assumptions of emissions reductions, generation mix, and electricity demand. As discussed in Section 3, IEA's scenario projects that U.S. electric power industry emissions would decline by nearly 90 percent by 2050 under a 2-degree transition scenario. PPL used a 50 percent reduction by 2050 as its benchmark. Additionally, PPL's analysis could be strengthened by expanding its quantitative analysis to include all of its assets, including distribution systems, and, as discussed in Section 4, by reviewing the potential physical impacts of climate change, including looking at how impacts may affect specific assets and the company as a whole. Notably, in January 2018, PPL announced a commitment to reduce carbon dioxide emissions 70 percent below 2010 levels by 2050.

Given that companies are only beginning to conduct climate strategy assessments with 2-degree analyses, it is expected that it may take continued engagement with stakeholders over time to make reports consistent with internal and external expectations.

Reference:

PPL Corporation, "PPL Corporation Climate Assessment", November 2017. Available at: https://www.pplweb.com/wp-content/uploads/2017/12/PPL-Corporation-Climate-Assessment-Report.pdf.

Table 6.1 identifies key elements of corporate disclosure that investors, customers, and other stakeholders will look for as part of a company's reporting. Investors seek public reports that clearly explain how companies are assessing potential future business conditions through scenarios. Instructive reports not only illuminate the key outputs of the scenarios, they also clearly explain the parameters, inputs, and assumptions associated with the analyses. A transparent discussion of the underlying assessment is essential to clearly communicate and substantiate the strategic insights gleaned from the process.

Building on a robust and transparent analytical foundation, investors want to understand how companies apply scenario analyses to inform company planning and strategies. Thorough disclosures include an objective assessment of the material risks and opportunities identified through the assessment and articulate how a company manages these uncertainties. Investors seek information on how scenario analyses and the insights they generate influence company strategy. They also want to understand how a company views the resilience of its strategy under future scenarios. Resilience of a strategy may be measured from a variety of metrics and stakeholder expectations. For example, how does a company foresee maintaining profitable operations while meeting a range of customer and stakeholder expectations, including reliable and competitive service, in light of future uncertainties?

Given that companies have only begun to develop climate strategy assessments, industry best practices for analytics and transparency have yet to be established in practice. As more companies develop and publish climate-related assessments, the key elements to be refined as companies and stakeholders become more versed in the process of developing and interpreting the results. The electric power industry would benefit from collaboration and information sharing across companies about the process of conducting a scenario analysis. More robust peer-to-peer review can help advance industry-wide tools and best practices and ultimately enhance the value of these assessments.

Table 6.1. Effectively Communicating Climate Strategy Assessments

ASPECT OF ASSESSMENT	PARAMETER	KEY ELEMENTS TO COMMUNICATE
Overarching	Geographic Scope	· Area of operations included in assessment · Operations not included in assessment
	Macroeconomic Inputs	· Population, demographics, economic growth, and other key factors
	Time Horizon	· Period covered by quantitative modeling · Period covered by qualitative assessments
	Covered Assets	· Assets included in the assessment · Assets not included in the assessment
	Process	· Internal process for developing scenarios and identifying physical impacts, informing company strategy, monitoring changing landscape, and engaging senior leadership
2-Degree Transition	Emission Reduction Trajectory	· Justification for reduction trajectory (existing modeling suggests the U.S. electric power industry would have to reduce emissions by about 90% by 2050) · Potential pace of emission reductions
	Electricity Demand	· Potential impact of energy efficiency, energy storage, electric vehicles, distributed energy technologies, and other key factors on demand, including how it affects load peaks
	Energy Technologies	· Outlook for future energy resources · Assumptions for fuel and technology costs, including both demand and supply-side · Generation and capacity of energy supply resources · Role of fossil fuel-based generation (with and without carbon capture and storage)
	Consumers, Policies and Market Structures	· Assumptions for consumer preferences · Role and assumptions for policy and market structures · Implications of policy and market assumptions on technology preferences and on costs
Physical Impacts	Acute Impacts	· Exposure of assets to short-term impacts including extreme heat, extreme precipitation and storms, storm surge, wildfires, and other potential acute climate impacts
	Chronic Impacts	· Exposure of assets to long-term impacts including increased temperatures; sea level rise; changes in precipitation patterns, water availability, and wind patterns; and other potential chronic climate impacts
Business Insights (Based on TCFD Recommended Disclosures)	Strategy	· Describe the climate-related risks and opportunities the company has identified over the short, medium, and long term · Describe the impact of climate-related risks and opportunities on the company's businesses, strategy, and financial planning · Describe the resilience of the company's strategy, taking into consideration different climate-related scenarios, including a 2-degree scenario
	Risk Management	· Describe the company's process for identifying and assessing climate-related risks · Describe the company's processes for managing climate-related risks · Describe how processes for identifying, assessing, and managing climate-related risks are integrated into the organization's overall risk management

APPENDIX A:
REVIEW OF SOURCES AND CONSIDERATIONS FOR INCORPORATING A 2-DEGREE TRANSITION INTO A SCENARIO

As introduced in Section 3, there are a number of important factors to consider when developing a scenario that reflects a 2-degree transition. Drawing from the more prominent existing reports and 2-degree modeling efforts, this Appendix reviews important considerations for developing a 2-degree transition scenario. These include what a 2-degree transition would mean for electric power industry emissions, generation, demand, energy technologies, policy and other key factors. Table A-1 lists the key reports and modeling efforts reviewed below.

Table A-1. Reports and Modeling Efforts that Provide Information on 2-Degree Energy Sector Transition Pathways

TITLE	DESCRIPTION
Energy Modeling Forum -24 (EMF-24) **"Study on U.S. Technology and Climate Policy Strategies** **(2014)**	EMF-24 is an academic research project organized by Stanford University to use cross-model comparisons to develop a more robust understanding of projected future climate and energy scenarios. The EMF-24 project presents the results of scenarios that model reduction pathways in U.S. GHG emissions of 50 percent and 80 percent below 2005 levels by 2050. The synthesis report includes a range of models with varying structures, covered sectors and gases, and geographic scope. **Reference:** Energy Modeling Forum, "EMF-24-Study on U.S. Technology and Climate Policy Strategies", Stanford University, August 1, 2014. Available at: https://emf.stanford.edu/projects/emf-24-us-technology-and-climate-policy-strategies.
International Energy Agency (IEA) **"World Energy Outlook"** **(2017, Issued Annually)**	The World Energy Outlook (WEO) is an annual publication produced by IEA that models long-term trends in the global energy system, including the electric, oil and gas, and transportation sectors. The WEO is a widely respected analysis used by industry, governments, and non-profits. The WEO is updated annually and includes global, regional, and country-specific energy sector information from a series of model runs. Within the WEO, IEA has historically modeled three scenarios: "New Policies Scenario," based on announced and existing global policy commitments on climate and energy; "Current Policies Scenario," that models the projected impact of current policies; and "450 Scenario" (WEO 450), that sets a pathway for the energy sector that is consistent with a 50 percent chance of achieving a 2 degree temperature target. A number of companies that have completed an analysis of 2-degree transitions have used the WEO 450 scenario as a central foundation In its 2017 WEO, IEA introduced the Sustainable Development Scenario (WEO SDS) that integrates sustainable development goals of achieving universal access to affordable and sustainable energy services by 2030, including actions to substantially reducing air pollution, and taking effective action to combat climate change. The SDS builds on and is broadly consistent with the 2016 WEO 450 scenario. When extended through 2100, the SDS would limit warming to a 1.7 to 1.8 degree rise in global temperatures. Finally, in addition to the WEO, IEA with the International Renewable Energy Agency also released a report in 2017 titled "Perspectives for the Energy Transition," that discusses pathways consistent with a 66 percent chance of staying below 2 degrees. **References:** International Energy Agency, "World Energy Outlook 2017", November 14, 2017. Available at: https://www.iea.org/weo2017/ International Energy Agency, "World Energy Outlook 2016", November 16, 2016. Available at: https://www.iea.org/newsroom/news/2016/november/world-energy-outlook-2016.html. International Energy Agency, "Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy System", 2017. Available at: https://www.iea.org/publications/insights/insightpublications/PerspectivesfortheEnergyTransition.pdf.

Table A-1. Reports and Modeling Efforts that Provide Information on 2-Degree Energy Sector Transition Pathways

TITLE	DESCRIPTION
Natural Resources Defense Council (NRDC) **"America's Clean Energy Frontier: The Pathway to a Safer Climate Future"** **(2017)**	In September 2017, NRDC released an analysis using the PATHWAYS model, a bottom-up energy system model developed by Energy + Environmental Economics (E3), to model a pathway to an 80 percent reduction in energy-related carbon dioxide emissions below 1990 levels by 2050. The report used cost data from the 2013 Annual Energy Outlook to allow for an apples-to-apples comparison to the "Pathways to Deep Decarbonization in the United States" report. **Reference:** Natural Resources Defense Council, "America's Clean Energy Frontier: The Pathway to a Safer Climate Future", September 2017. Available at: https://www.nrdc.org/sites/default/files/americas-clean-energy-frontier-report.pdf.
The Deep Decarbonization Pathways Project (DDPP) **"Pathways to Deep Decarbonization in the United States"** **(2014)**	The DDPP is an international collaborative initiative that models country-specific GHG emission strategies that are consistent with achieving 2-degree targets. The DDPP modeled scenarios where the U.S. achieves an 80 percent reduction below 1990 levels by 2050. The DDPP modeled four scenarios including: High Renewables Case, High Nuclear Case, High CCS Case, and Mixed Case. The Mixed Case is the main case in the DDPP report, intended to incorporate a greater mix of technologies for illustrative purposes. The DDPP primarily used the PATHWAYS model and relied on Global Change Assessment Model (GCAM), a global integrated assessment model, to model for non-energy related emissions. The US DDPP was developed jointly between E3, Lawrence Berkeley National Laboratory, and Pacific Northwest National Laboratory and published in 2014. **Reference:** Deep Decarbonization Pathways Project, "Pathways to Deep Decarbonization", 2014. Available at: http://unsdsn.org/wp-content/uploads/2014/09/US-Deep-Decarbonization-Report.pdf.
The White House **"U.S. Mid-Century Strategy For Deep Decarbonization"** **(2016)**	In November 2016, as part of the Paris Agreement, the Obama Administration submitted the U.S. Mid-Century Strategy for Deep Decarbonization (U.S. MCS) to the UNFCCC, charting a range of scenarios to achieve an 80 percent reduction in U.S. GHG emissions below 2005 levels by 2050. The White House worked closely with the Environmental Protection Agency, Department of Energy, Department of Agriculture and Department of State to develop the report. A benefit of the U.S. MCS is that it combined data from multiple models and sources to develop a full economy-wide strategy for all GHGs, including land-sector emissions and sinks and non-CO_2 emissions. Therefore, the emissions reductions in the energy sector are optimized to reflect the level of emissions reductions achieved in other sectors. The report primarily relied on GCAM but also included model output from the Global Timber Model, DOE's National Energy Modeling System (NEMS), DOE Advanced Technology NEMS modeling, EPA's Marginal Abatement Cost Model, and other sources. The primary scenario referenced in this report is the Benchmark scenario. **References:** The White House, United States Government, "United States Mid-Century Strategy for Deep Decarbonization", November 2016. Available at: http://unfccc.int/files/focus/long-term_strategies/application/pdf/mid_century_strategy_report-final_red.pdf. The White House, United States Government, "United States Mid-Century Strategy for Deep Decarbonization Documentation and Output Data", November 2016. Available at: http://unfccc.int/files/focus/long-term_strategies/application/pdf/us_mcs_documentation_and_output.pdf.

While each of the resources in **Table A-1** could inform the development of 2-degree transition scenarios, the IEA WEO SDS and U.S. MCS Benchmark scenario are particularly useful reference points for companies in the U.S. electric power industry. The sections that follow provide insights from all models but focus specifically on these two given their robustness and relevance.

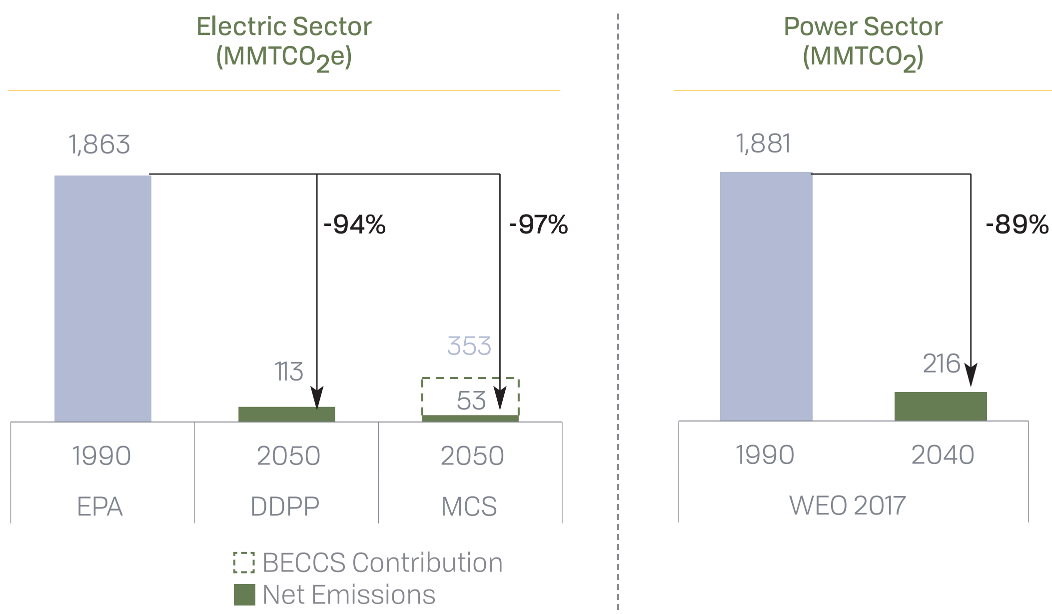
Emission Reduction Trajectories

Achieving an 80 percent reduction in net economy-wide GHG emissions would require sustained actions across all economic sectors, including the electric power industry. However, given the difficulty of extracting emissions from many sectors of the economy and due to the relatively lower cost and greater feasibility of decarbonizing the electric power industry, it is anticipated that the U.S. electric power industry need to reduce emissions by more than 80 percent.

The existing literature suggests that a reduction of emissions from the U.S. electric power industry of at least 90 percent from 1990 or 2005 levels by 2050 (**Figure A-1**) would be consistent with an 80 percent reduction target for the entire U.S. economy.* Uncaptured residual carbon dioxide emissions from the entire U.S. electric power industry in-line with the projections would be equivalent to the annual emissions from between 13 and 54 modern day coal power plants.[58] Based on the U.S. MCS analysis, annual emissions from the electric power industry in 2050 would be equivalent to current annual electric power industry emissions in Georgia.[59]

While the rate of reduction would not be distributed equally across all regions, all companies would need to make substantial changes to meet a 2-degree target. Companies should consider what unique market, economic, political, and technological barriers or opportunities would affect their relative burden of emissions reductions. Interim emission reductions (e.g., by 2030 or 2040) could be established using existing state targets or other assumptions about the expected rate of reductions. However, it is important to recognize the pace and scale of the transition and create plausible transition pathways. Evaluating the implications of an emissions reduction trajectory that is in line with a 2-degree transition is a first-order question for any climate strategy assessment. The following discussion addresses potential driving forces such as technology advances that would shape a specific pathway for a 2-degree transition. The plausibility, and therefore, the value of any scenario will rely on the transparency of assumptions that show how the various

Figure A-1. 1990 Emissions and Comparisons Across Models (2040 and 2050)



Note: MCS estimate includes contribution of biomass energy with CCS (BECCS) but does not account for upstream emissions associated with biomass farming and transportation and indirect land-use impacts.

Power Sector emissions include industrial heat

Sources:

MJB&A Analysis.

EPA: U.S. EPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2015", April 2017. Available at: https://www.epa.gov/sites/production/files/2017-02/documents/2017_complete_report.pdf.

DDPP (Mixed Case): Deep Decarbonization Pathways Project, "Pathways to Deep Decarbonization", 2014. Available at: http://unsdsn.org/wp-content/uploads/2014/09/US-Deep-Decarbonization-Report.pdf.

MCS (Benchmark): The White House, United States Government, "United States Mid-Century Strategy for Deep Decarbonization Documentation and Output Data", November 2016. Available at: http://unfccc.int/files/focus/long-term_strategies/application/pdf/us_mcs_documentation_and_output.pdf.

WEO 2017 (Sustainable Development Scenario): International Energy Agency, "World Energy Outlook 2017", November 14, 2017. Available at: https://www.iea.org/weo2017/.

* The justification for this is discussed in depth in Section 3

driving forces could lead to a level of change within the power industry that equates to the targeted reduction in emissions. This level of analytical rigor is fundamentally different than modeling a sensitivity with a price on greenhouse gas emissions.

Electricity Demand

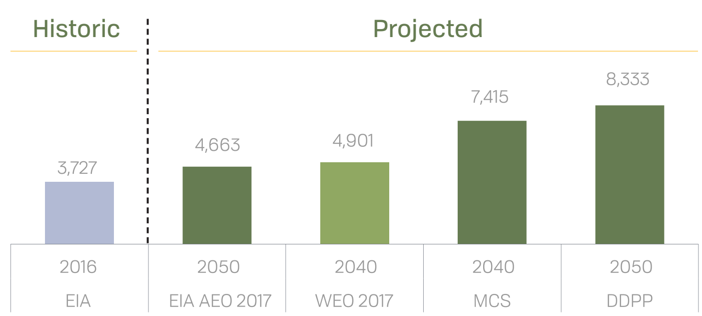
Evaluating future electricity demand is difficult under any scenario, but the challenge becomes even more pronounced when considering a 2-degree transition. Over the past two decades, end uses of electricity have become significantly more energy efficient. Recently, demand for electricity in the U.S. has been relatively flat as a result of improved residential, commercial, and industrial efficiency.[60] Over the next several decades, under a reference case, the Energy Information Administration (EIA) projects that electricity demand will increase slowly at a rate of 0.7 percent per year.[61] The outlook becomes more complicated under a 2-degree transition where a variety of emission reduction strategies apply both positive and negative pressure on future electricity demand. Increased energy efficiency and expansion of behind-the-meter energy resources could curtail growth in demand for grid-supplied electricity, while other forces, such as increased electrification of vehicles, home heating, and industrial processes, could increase demand.

Most 2-degree modeling stresses the importance of prioritizing energy efficiency first, not only because it is considered the lowest-cost opportunity, but because it eases the need for new electric generating resources. Energy efficiency prevents overbuild of conventional fossil fuel-based generation while also relieving pressure on supply from renewable generation. Reducing electricity and heating demand from residential and commercial buildings, reducing heat losses in industrial processes, investing in more efficient transportation, and encouraging smarter and denser urban development would lower GHG emissions in the near- and long-term and make replacing carbon-intensive fuels with zero-carbon sources more achievable. The DDPP Mixed Case shows energy efficiency accounting for 20 percent of total decarbonization in its assessment. Furthermore, efficiency gains often have cross-cutting, compounding effects on GHG reduction goals. For instance, promoting dense urban development would likely increase efficiency while decreasing transportation related emissions.

Distributed energy resources, which include rooftop solar, distributed energy storage, combined heat and power, and small wind have the potential to lower demand for grid-supplied electricity. These resources have grown rapidly in the last decade, spurred by increasingly competitive costs and robust policy incentives. This trend is already reshaping the load curve in many markets across the country as well as presenting other business challenges. The 2-degree assessments reviewed for this framework do not offer specific insights on the future of distributed energy resources, but current trends and many other assessments point to continued growth. While these relatively new resources introduce challenges, many of them also present new opportunities to support decarbonization of the grid. For example, energy storage can help alleviate congestion, provide real-time load balancing, and address imbalances between hourly peak electricity supply and peak electricity demand.

Despite downward pressure on energy demand from greater energy efficiency and the potential shift to more behind-the-meter, distributed energy resources, all 2-degree scenarios project that grid-supplied electricity generation will rise, sometimes by large margins (see Figure A-2 below).

Figure A-2. Electricity Generation Comparisons (TWh)



Sources:

MJB&A Analysis.

EIA and EIA AEO 2017: EIA, "Annual Energy Outlook 2017", January 5, 2017. Available at: https://www.eia.gov/outlooks/archive/aeo17/.

WEO 2017 (Sustainable Development Scenario): International Energy Agency, "World Energy Outlook 2017", November 14, 2017. Available at: https://www.iea.org/weo2017/.

MCS (Benchmark): The White House, United States Government, "United States Mid-Century Strategy for Deep Decarbonization Documentation and Output Data", November 2016. MCS (Benchmark): The White House, United States Government, "United States Mid-Century Strategy for Deep Decarbonization Documentation and Output Data", November 2016. Available at: http://unfccc.int/files/focus/long-term_strategies/application/pdf/us_mcs_documentation_and_output.pdf.

DDPP (Mixed Case): Deep Decarbonization Pathways Project, "Pathways to Deep Decarbonization", 2014. DDPP (Mixed Case): Deep Decarbonization Pathways Project, "Pathways to Deep Decarbonization", 2014. Available at: http://unsdsn.org/wp-content/uploads/2014/09/US-Deep-Decarbonization-Report.pdf.

Deep decarbonization analyses show an expanded role for electricity, specifically carbon-free electricity, as a means to displace fossil fuels and reduce GHG emissions. Therefore, electricity demand rises to meet a larger share of overall energy demand. Currently, with the exception of some electric vehicles and biofuels, petroleum supplies virtually all energy for transportation and is responsible for over a quarter of total gross GHG emissions in the United States. Even with changes in transportation (such as automated vehicles and ride-sharing), vehicle-miles-traveled are projected to continue to grow through midcentury.[62] Therefore, achieving emissions reductions will require both electrification of key sectors and broad deployment of carbon-free electricity to supply this new demand.

While all the assessments reviewed for this framework project growth in electric vehicles, they offer a wide range of plausible future scenarios and assumptions depending on expected policies and consumer preferences (**Table A-2**). The U.S. MCS Benchmark scenario is especially bullish and estimates that over 56 percent of passenger miles traveled in 2050 will be from electric vehicles and 13 percent from hybrid vehicles. In total, the MCS Benchmark scenario estimates that electricity will supply 24 percent of total energy used in the transportation sector. Similarly, the DDPP Mixed Case projects that electricity will be the "dominant energy carrier for passenger vehicle transport" in most of its cases. Conversely, the WEO SDS projects that only 15 percent of energy for transport will be supplied from electricity in 2040 with oil continuing to supply roughly half of all energy for transportation. Instead of electricity, both WEO's SDS and 450 project higher use of biofuels (25 percent of total transportation energy use from biofuels in SDS) to reduce transportation sector emissions.

There are similar trends in the industrial energy-use findings. The WEO SDS projects an expansion in the use of bioenergy to reduce industrial emissions whereas, in the U.S. MCS Benchmark scenario, the U.S. doubles the share of electricity for industry. Like the WEO, the DDPP Mixed Case projects lower rates of industrial electrification and instead models greater electrification in homes and buildings (**Table A-2**). The divergence among models is likely due to different assumptions about the cost and technical difficulties of electrification and fuel-switching in the industrial sector which is much more heterogeneous and process-specific than other sectors.

Varying assumptions of efficiency and electrification have an impact on both the total projected future electricity demand across the scenarios as well as the

Table A-2. Electrification Assumptions Across Models

<table>
<tr><th rowspan="2">SECTOR</th><th colspan="4">SHARE OF ELECTRICITY PROVIDING TOTAL FINAL ENERGY</th></tr>
<tr><th>2015
WEO 2017 (SDS)</th><th>2040
WEO 2017 (SDS)</th><th>2050
MCS BENCHMARK</th><th>2050
DDPP MIXED CASE</th></tr>
<tr><td>Residential</td><td rowspan="2">52%
in buildings sector</td><td rowspan="2">58%
in buildings sector</td><td rowspan="2">74%
in buildings sector</td><td>94%</td></tr>
<tr><td>Commercial</td><td>90%</td></tr>
<tr><td>Transport</td><td>0.2%</td><td>15%</td><td>24%</td><td>28%*</td></tr>
<tr><td>Industry</td><td>26%</td><td>26%</td><td>54%</td><td>27%</td></tr>
</table>

* The DDPP percentage is higher partially due to the fact that this is reporting passenger vehicles only. Electric passenger vehicles will see larger rates of penetration than other subsectors within the transportation sector. Freight transportation (rail, HDV, aviation, shipping) will have much lower rates of electrification.

Sources:

MJB&A Analysis.

WEO 2017 (Sustainable Development Scenario): International Energy Agency, "World Energy Outlook 2017", November 14, 2017. Available at: https://www.iea.org/weo2017/.

MCS (Benchmark): The White House, United States Government, "United States Mid-Century Strategy for Deep Decarbonization Documentation and Output Data", November 2016. Available at: http://unfccc.int/files/focus/long-term_strategies/application/pdf/us_mcs_documentation_and_output.pdf.

DDPP (Mixed Case): Deep Decarbonization Pathways Project, "Pathways to Deep Decarbonization", 2014. Available at: http://unsdsn.org/wp-content/uploads/2014/09/US-Deep-Decarbonization-Report.pdf.

demand characteristics. The U.S. MCS Benchmark scenario strategy projects that electricity generation would increase 80 percent from 2016 levels in order to meet demand from electrified end-uses. Similarly, the DDPP Mixed Case projects that electricity generation would need to double by 2050. Conversely, WEO SDS projects a 14 percent increase in total U.S. electric generation from 2015 through 2040. The move to greater electrification further stresses the importance of energy efficiency in 2-degree scenarios. Without the investments in energy efficiency, the electricity grid would have to absorb a much larger growth in new electricity demand by 2050.

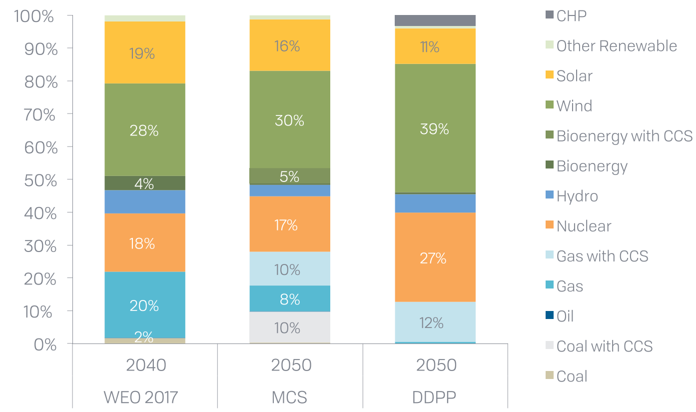
Electricity Generation Technologies

The mix of technologies that are used to generate electricity in an emissions-constrained environment will depend on their costs and the impact of policies that promote or potentially constrain certain types of resources. The analyses reviewed for this framework provide different perspectives on the outlooks for various technologies (**Figure A-3**). In the United States, the WEO SDS projects that renewables, including hydro, would supply over 60 percent of generation in 2040 with nuclear providing an additional 18 percent. The analysis finds that wind capacity would increase more than five-fold by 2040 from 73 GW of installed capacity in 2015 to roughly 416 GW in 2040. Installed capacity of solar photovoltaic and concentrated solar totals 494 GW in 2040, accounting for 19 percent of total generation. Conversely, coal generation declines from 34 percent of total generation in 2015 to 2 percent in 2040.

The U.S. MCS Benchmark scenario finds that electricity would be generated almost entirely from low-carbon sources by 2050, including solar, wind, nuclear, natural gas combined with carbon capture and storage (CCS), and coal with CCS. In this modeling, nearly all remaining coal plants generating electricity have installed CCS systems and more than half of the natural gas generation is from gas plants with CCS systems. In total, 92 percent of the generation mix is comprised of low-carbon technologies by 2050 with 55 percent coming from renewables (including 15 percent from solar and 30 percent from wind), 17 percent nuclear power, and 20 percent fossil-fuels with CCS.

The pace and scale of this transition for the U.S. generation fleet is significant. Investments in new wind and solar capacity would need to accelerate from current deployment levels. In 2016, the two technologies

Figure A-3. Share of Generation – Comparisons Across Models (2040 and 2050)



Sources:

MJB&A Analysis.

EIA and EIA AEO 2017: EIA, "Annual Energy Outlook 2017", January 5, 2017. Available at: https://www.eia.gov/outlooks/archive/aeo17/.

WEO 2017 (Sustainable Development Scenario): International Energy Agency, "World Energy Outlook 2017", November 14, 2017. Available at: https://www.iea.org/weo2017/.

MCS (Benchmark): The White House, United States Government, "United States Mid-Century Strategy for Deep Decarbonization Documentation and Output Data", November 2016. MCS (Benchmark): The White House, United States Government, "United States Mid-Century Strategy for Deep Decarbonization Documentation and Output Data", November 2016. Available at: http://unfccc.int/files/focus/long-term_strategies/application/pdf/us_mcs_documentation_and_output.pdf.

DDPP (Mixed Case): Deep Decarbonization Pathways Project, "Pathways to Deep Decarbonization", 2014. DDPP (Mixed Case): Deep Decarbonization Pathways Project, "Pathways to Deep Decarbonization", 2014. Available at: http://unsdsn.org/wp-content/uploads/2014/09/US-Deep-Decarbonization-Report.pdf.

combined for a total of 16.4 GW of new capacity.[63] The U.S. MCS Benchmark scenario projects that wind and solar deployment would reach, on average, about 30 GW a year from 2016 to 2035 and ramp up installations to over 50 GW per year between 2036 and 2050. To put this in context, from 2000 to 2010, installations of natural gas combined cycle turbines averaged 21 GW per year, with 56 GW coming online in 2002. At its height in 1980, new coal installations totaled 15 GW. **Table A-3** reviews findings for additional technologies. The rapid change and acceleration in generation investments would have significant implications for the industry as companies plan and finance new facilities and cope with the potential for reduced utilization and retirement of existing fossil-fired power plants.

Table A-3. Review of Non-Wind and Solar Technology Deployment under 2-Degree Scenarios

TECHNOLOGY	DISCUSSION
Fossil Fuel-Fired Power Plants (with CCS)	To a large extent, the contributions from fossil resources to electricity generation in 2-degree analyses depend on the availability of CCS. In the United States, WEO SDS projects that coal generation in 2025 would be 35 percent of 2015 levels and would continue to decline to supply less than 2 percent of total generation by 2040. The U.S. MCS projects 10 percent of U.S. electricity will be supplied from coal with CCS and virtually no coal-powered electricity without CCS. Compared to coal, natural gas markets serve a larger role through 2040. In 2040, WEO SDS projects natural gas generation would decline by 28 percent from 2015 levels but would still supply 20 percent of U.S. generation. The U.S. MCS projects 18 percent of generation from natural gas in 2050 with more than half of remaining gas generation controlled with CCS. Both the DDPP and U.S. MCS examine cases where CCS deployment is limited. In these cases, other technologies such as nuclear and renewables are more heavily relied on to meet the GHG reduction targets.
Nuclear Power	In nearly all 2-degree analyses, nuclear remains a central piece of U.S. generation. For instance, in the U.S. MCS, nuclear generation increases from 805 TWh in 2005 to 1250 TWh in 2050. Similarly, the DDPP estimates that nuclear would supply between 9 to 40 percent of generation in 2050 across its five cases (27 percent in its central case). WEO SDS estimates nuclear generation will increase from 830 TWh in 2015 to 869 TWh in 2040. In cases where renewable deployment falls short or where fossil-CCS technologies fail to deliver, the United States' reliance on nuclear to supply zero-carbon generation is greater. While traditional nuclear power serves the bulk of current load, advanced nuclear technologies, including small modular reactors, may play a larger role in the decades to come.
Energy Storage	Energy storage technology, including battery storage, is scaling up at a rapid rate and has the potential to provide important grid services. In 2015, the United States doubled the installed capacity of advanced energy storage. Energy storage has the potential to smooth supply peaking when coupled with solar generation, improve grid reliability, balance load, provide back-up supply, decrease costs, and reduce emissions if paired with renewable energy. Electric vehicles have the potential to both serve as energy storage resources and as demand response resources, by shifting time of use of charging. While energy storage on a whole provides benefits to the electric grid, battery storage coupled with distributed solar may lead to more decentralized electricity markets and decrease revenue streams for electric power companies.
Biomass (with CCS)	The role of carbon negative technologies, such as biomass with CCS, becomes more important in mid- to late-century in decarbonization analyses as it becomes more difficult and more expensive to extract remaining emissions from the economy and to address the existing stock of atmospheric carbon dioxide. In nearly all climate models, the world must achieve net negative emissions in late century in order to remain on track to achieve 2 degrees. Most models suggest that these technologies will need to start as early as 2020. The U.S. MCS shows biomass with CCS supplying five percent of electricity in 2050. Other models do not include biomass with CCS.

Role of Consumers, Policies and Market Structures

In developing assumptions for a 2-degree transition, it is important not to solely consider the technical challenges and availability of future technologies in isolation. The pathway to deep carbon reductions will also be shaped by consumer demands and a range of policies and market structures that define the competitive landscape. A close examination of current trends and past lessons can provide valuable insights to inform plausible market and policy forces.

An increasing number of consumers and ratepayers want more control over their energy sourcing and use, including favoring generation from specific technologies, installing distributed generation technologies, controlling time of use, and cutting consumption through efficiency improvements.[64] According to public opinion polling, Americans are increasingly concerned about climate change and favor actions to begin to address it.[65] At the same time, corporations are setting climate and clean energy goals, some of which align with 2-degree targets. As of January 2018, 122 multinational companies, including 44 headquartered in the U.S., had committed to sourcing 100 percent of their electricity from renewable energy sources through the RE100 initiative.[66] Measured by electricity demand, the commitments to RE100 increased 49 percent in one year. A 2016 survey of large U.S. companies, many of which spend more than $100 million per year on electricity, 72 percent responded that they were actively pursuing renewable energy procurement targets.[67] Increasing public awareness and concern about the risks and impacts of climate change could make companies in the electric power industry vulnerable to public campaigns against companies with large fossil fleets, nuisance lawsuits, or other political, legal, and public image related challenges. Consumer interest in renewable energy could create new business opportunities for companies in the electric power industry.

While consumer and corporate trends will continue to evolve, a key driver for a 2-degree transition scenario will be climate and clean energy policies pursued by local and state governments as well as the federal government. The ambition of these policies will create risks and opportunities for companies in the electric power industry.

While consumer and corporate trends will continue to evolve, a key driver for a 2-degree transition scenario will be climate and clean energy policies pursued by local and state governments as well as the federal government. The ambition of these policies will create risks and opportunities for companies in the electric power industry. Policies could favor the development of specific technologies, such as offshore wind or electric vehicles, influencing the way companies evaluate strategies to meet an emissions trajectory, or the policies could be technology-neutral and focus on creating a market for trading emissions. The types of climate-related policies that could impact the electric power industry include:

- **Comprehensive GHG emissions pricing (e.g., cap-and-trade or carbon tax):** Economic literature suggests that most efficient and cost-effective way to cut emissions would be a mechanism that places a price on GHG emissions. This could be in the form of a cap-and-trade program that sets a declining emissions cap or a carbon tax. GHG emission pricing mechanisms are already in place in a number of states. California has a comprehensive cap-and-trade program that covers 85 percent of its emissions. States in the Northeast have adopted a cap-and-trade program, the Regional Greenhouse Gas Initiative, for electric utilities. Virginia, New Jersey, Oregon, and Washington are also considering joining or adopting market-based cap-and-trade programs.
- **Emission standards:** Governments could also pursue command-and-control policies that require units to meet specific emission standards. In 2015, U.S. EPA promulgated emission standards that apply to new, modified, and reconstructed fossil fuel-fired power plants. These standards and any future emission standards impact the decision-making process for companies in the electric power industry as they are considering investments.
- **Electrical generation or procurement mandates (e.g., renewable portfolio standards):** Generation or procurement mandates do not regulate GHGs directly but may reduce emissions by creating incentives to increase the deployment of low-carbon generation sources. Overall, technology-specific mandates are less cost effective at reducing emissions than pricing schemes but have other potential benefits, such as encouraging local investment or lowering the costs associated with technologies. Twenty-nine states and the District of Columbia have adopted renewable portfolio standards that require electric utilities to deliver a minimum share of electricity from renewable or alternative energy sources.[68] The existing goals are not sufficient to reduce emissions in the electric power industry to the levels implied by a 2-degree target but could potentially be increased. For instance, in 2017, California came close to passing a 100 percent renewable generation mandate, which would have had significant impacts on the state's electric grid and GHG emissions.

In addition to these major climate and electric power industry related policies, companies can consider how other complementary, overlapping, or counteractive policies may impact technology preferences in their analyses. These include:

- Clean energy technology tax incentives (e.g., production tax credit, investment tax credit);
- National and subnational funding for research and development;
- Transportation policies (e.g., emissions control regulations, electric vehicle mandates, infrastructure funding);
- Energy efficiency programs;
- Industrial regulation (e.g., emissions control regulations); and
- Other incentives (e.g., residential net-metering).

As many of these policies and incentives already exist at a local, state, or federal level, companies in the electric power industry have likely included a number of these polices within existing planning exercises. A 2-degree transition analysis can be used to explore the potential for existing policies for strengthened or new policies to be implemented and the potential impact of those policies on corporate strategy. It is unlikely that a company would face only one policy related to GHG emission reductions. Rather, much as it is today, a variety of overlapping federal and state initiatives will combine to push GHG reductions and promote transitions to clean energy.

Each policy will have different impacts on companies in the electric power industry. For instance, policies that offer little flexibility and little opportunity for trading may be more costly to businesses than market-based programs. In contrast to their detailed analysis of the broad economic implications of transitioning to a 2-degree energy system, most of the modeling exercises are largely silent on the policies needed to get there. Therefore, there is greater onus on companies to explore and consider potential state and federal policy mechanisms consistent with a 2-degree target and the associated risks and opportunities. These overlapping regional, political, and policy-related factors are very complex and difficult to fully model or quantitatively analyze. However, they are also critically important to evaluate.

In contrast to their detailed analysis of the broad economic implications of transitioning to a 2-degree energy system, most of the modeling exercises are largely silent on the policies needed to get there. Therefore, there is greater onus on companies to explore and consider potential state and federal policy mechanisms consistent with a 2-degree target and the associated risks and opportunities.

APPENDIX B:
REVIEW OF SOURCES AND CONSIDERATIONS FOR INCORPORATING PHYSICAL IMPACTS INTO A SCENARIO

While no single event can be attributed to climate change, the U.S. electric power industry is already experiencing the impacts of climate change. As introduced in Section 4, these impacts are diverse, wide-ranging, and poised to result in substantial costs and service disruptions in the electric power industry. This section examines some of the major climate impacts facing companies in the electric power industry.

Table B-1 (following page) presents resources that companies may reference in conducting physical impacts assessments. These include the U.S. NCA which is a comprehensive, current, and detailed report on how climate change is affecting and is projected to further impact the United States. In addition to the NCA, DOE has published two reports that take a closer look at the impacts on the electric and help companies begin to take these impacts into consideration in their planning process.

In addition to these comprehensive resources, researchers at government agencies and national laboratories have developed a range of tools to help companies map and assess data. These include tools for downsizing national-level datasets for use in specific regions of the country, which can be a critical component for translating general climate change impacts (e.g., increased heat waves) to local impacts that should be considered as part of a climate strategy assessment. **Table B-2** (page 40) provides a select summary of some of the more prominent tools.

While no single event can be attributed to climate change, the U.S. electric power industry is already experiencing the impacts of climate change. As introduced in Section 4, these impacts are diverse, wide-ranging, and poised to result in substantial costs and service disruptions in the electric power industry.

Table B-1. Key Resources for Assessing Vulnerabilities to Climate Change

TITLE	DESCRIPTION
DOE **"Climate Change and the Electricity Sector: Guide for Climate Change Resilience Planning"** **2016**	In 2016, DOE released a comprehensive step-wise guide for energy companies to use in assessing their vulnerability to climate change and building in measures that make their business more resilient to climate impacts. The report provides useful links to existing resources for assessing climate vulnerability and lists out case studies of actions companies in the electric power industry are already taking. **Reference:** U.S. DOE, "Climate Change and the Electricity Sector: Guide for Climate Change Resilience Planning", September 2016. Available at: https://energy.gov/sites/prod/files/2016/10/f33/Climate%20Change%20and%20the%20Electricity%20Sector%20Guide%20for%20Climate%20Change%20Resilience%20Planning%20September%202016_0.pdf.
DOE **"U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather"** **2013**	This report discusses projected impacts due to climate change and their effect on the U.S. energy sector. This includes the electricity sector but also oil and gas operations and biofuels. **Reference:** U.S. DOE, "U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather", July 2013. Available at: https://energy.gov/sites/prod/files/2013/07/f2/20130716-Energy%20Sector%20Vulnerabilities%20Report.pdf.
USGCRP **3rd and 4th National Climate Assessments** **2018, 2017, and 2014**	The U.S. National Climate Assessment is a comprehensive, multiagency report published by the U.S. Global Change Research Program detailing the full range of impacts of climate change on all sectors in the United States. The 3rd National Climate Assessment, which was published in 2014, includes supplemental chapters and materials, including a chapter dedicated to the Energy Sector, and regional summaries. At the time of the publication of this report, the U.S. government had released the first volume of the 4th National Climate Assessment which reflects the latest science on climate change. Subsequent volumes will provide more detailed information on the projected impacts of climate change to regions and sectors. These are scheduled to be released in mid-2018. **References:** U.S. Global Change Research Program (USGCRP), "3rd National Climate Assessment", 2014. Available at: https://nca2014.globalchange.gov/report. U.S. Global Change Research Program (USGCRP), "4th National Climate Assessment: Volume 1", 2017. Available at: https://science2017.globalchange.gov/.
California Public Utilities Commission **Climate Adaptation in the Electric Sector: Vulnerability Assessments and Resiliency Plans** **2016**	Several of California's investor-owned utilities are part of the DOE Partnership for Energy Sector Climate Resilience which aims to help electric companies prepare for climate change. California's report provides guidelines to help California utilities plan for impacts pertinent to regional risks. **Reference:** California Public Utilities Commission, "Climate Adaptation in the Electric Sector: Vulnerability Assessments and Resiliency Plans", January 1, 2016. Available at: http://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/About_Us/Organization/Divisions/Policy_and_Planning/PPD_Work/PPD_Work_Products_(2014_forward)/PPD%20-%20Climate%20Adaptation%20Plans.pdf.
New York City **"A Stronger More Resilient New York"** **2013**	In response to Hurricane Sandy, New York is working to make its utilities more resilient to the impacts of climate change, including tropical storms and sea level rise. **Reference:** City of New York, "A Stronger More Resilient New York", June 11, 2013. Available at: http://s-media.nyc.gov/agencies/sirr/SIRR_singles_Lo_res.pdf.
Boston, Massachusetts **"Climate Ready Boston"** **2016**	In 2016, the city of Boston launched its Climate Ready Boston initiative aimed at helping the city plan for future impacts of climate change. Its inaugural report combines projected climate impacts, such as sea level rise and extreme heat, with near and long-term implementation strategies with goals and targets. **Reference:** City of Boston, "Climate Ready Boston", December 2016. Available at: https://www.boston.gov/departments/environment/climate-ready-boston.

Table B-2. Physical Impact-Related Tools for Mapping and Assessing Risks

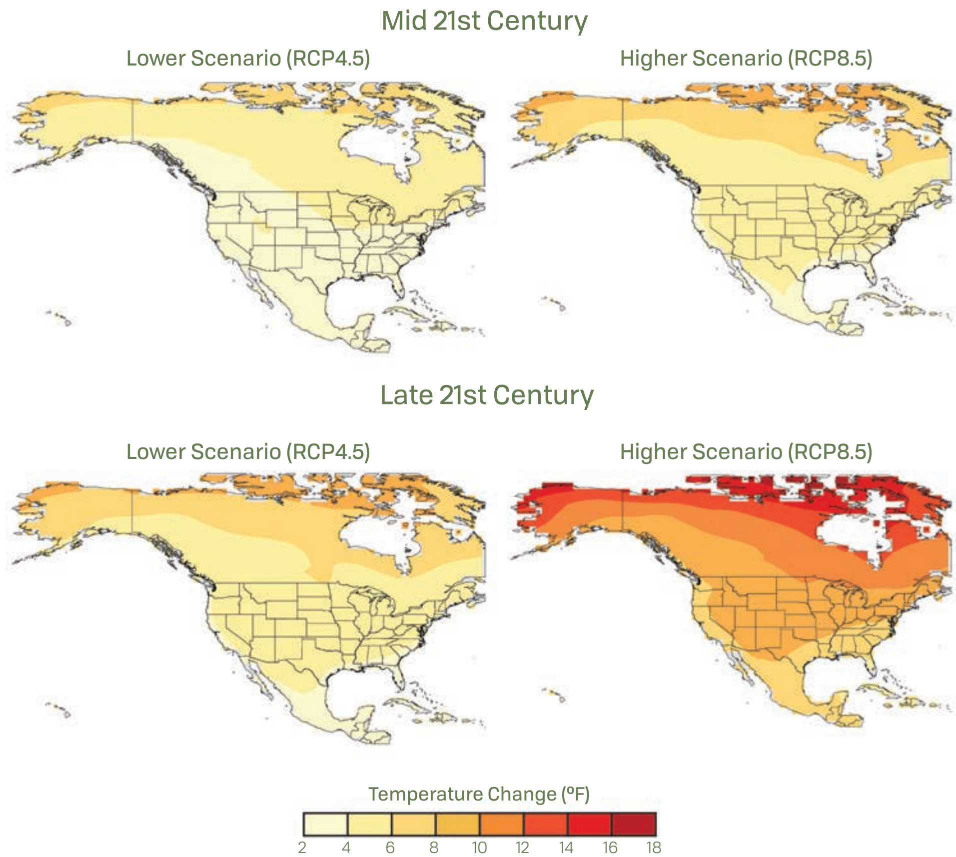
TITLE	DESCRIPTION
GENERAL	
IPCC: **Global Emission and Temperature Scenarios**	The IPCC has modeled a number of scenarios corresponding to different emission reduction pathways and radiative forcing. The RCP2.6 scenario assumes radiative forcing will increase to 2.6 watts per square meter by 2100, leaving the world with greater than 50% changes of remaining below 2 degrees. The RCP4.5 scenario assumes less ambitious emissions reduction with warming reaching 2.3-2.9 degrees C by 2100. The RCP8.5 assumes very limited emission reductions with temperatures rising to 4.1-4.8 degrees C by 2100. IPCC modeled the climate impacts associated with these scenarios. **Reference:** Intergovernmental Panel on Climate Change, "Climate Change 2014 Synthesis Report", 2015. Available at: https://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full.pdf.
USGCRP: **Climate Resilience Toolkit**	The U.S. Global Change Research Program developed the Climate Resilience Toolkit, an extensive database of dozens of mapping and planning tools for state governments, municipalities, agencies, and businesses to prepare for climate impacts. The database allows users to search by tool, region, impact, and sector of the economy. **Reference:** U.S. Climate Resilience Toolkit, "The Climate Explorer," USGCRP, online at: https://toolkit.climate.gov/climate-explorer2/.
California **Cal-Adapt Climate Tools**	Provides tools and data for projected climate impacts for the state of California. **Reference:** Cal-Adapt, "Climate Tools". Available at: http://cal-adapt.org/.
TEMPERATURE, EXTREME HEAT, PRECIPITATION, AND DROUGHT	
Lawrence Livermore National Laboratory: **Coupled Model Inter-comparison Project Phase 5**	Lawrence Livermore National Laboratory manages the Coupled Model Inter-comparison Project which provides multi-model climate projection output at a national and regional level, including temperature and hydrology projections. **Reference:** Lawrence Livermore National Laboratory, "Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections", October 2016. Available at: https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/#Welcome.
National Center for Atmospheric Research: **Climate Change Scenarios GIS data portal**	This portal provides GIS data and maps of current and future climate conditions under various IPCC warming scenarios. **Reference:** National Center for Atmospheric Research, "Climate Change Scenarios GIS Data Portal". Available at: https://gisclimatechange.ucar.edu/inspector.
EPA: **BASINS Climate Assessment Tool**	EPA's BASINs tool projects the effects of climate change on streamflow and water quality at the water-basin level. **Reference:** U.S. EPA, "BASINS Climate Assessment Tool". Available at: https://www.epa.gov/exposure-assessment-models/basins-climate-assessment-tool-tutorials.
SEA LEVEL RISE, STORM SURGE, COASTAL STORMS AND TROPICAL STORMS	
NOAA: **Sea Level Rise Viewer**	NOAA's Sea Level Rise Viewer is a GIS mapping platform that displays the coastal inundation associated with various sea level rise scenarios. **Reference:** NOAA Office of Coastal Management, "DigitalCoast — Sea Level Rise Viewer". Available at: https://coast.noaa.gov/digitalcoast/tools/slr.
DOE: **Sea Level Rise and Storm Surge Effects on Energy Assets**	This tool overlays sea level rise data for 10 U.S. cities with existing energy assets, including power plants, substations, and refineries, to map which resources are at risk of inundation. **Reference:** DOE Office of Electricity Delivery and Energy Reliability, "Sea Level Rise and Storm Surge Effects on Energy Assets", October 12, 2017. Available at: http://www.arcgis.com/home/item.html?id=e463abadcd9c4ef7982ae431e3fca7e7.

Temperature and Extreme Heat

Climate change will lead to both increases in regional seasonal average air temperatures and in the frequency and duration of heat waves and temperature extremes (Figure B-1).[69] According to the 4th NCA, the average temperature in the U.S. has risen between 0.7 to 1 degrees since 1895,[*,70] with the majority of this warming occurring since the 1970s.[71] Temperatures in 2017 were the third warmest on record for the U.S. and it was the twenty-first consecutive year that average annual temperature exceeded the average.[72] Under pathways consistent with 2 degrees of warming, the United States would experience a 1.5 to just over 2 degree[†] increase in average annual temperatures by 2100. Under higher emissions scenarios, the change could be more severe, rising by between 3 and 6 degrees by 2100.[73,‡] In addition to rising seasonal average temperatures, the 4th NCA anticipates greater temperature extremes due to climate change will result in extended periods of intense heat waves.

Increasing temperatures will directly impact the electric power industry in several ways. DOE's 2013 U.S. Energy Sector Vulnerabilities report notes that these include impacts to thermoelectric, hydroelectric, and solar generation; biofuel production; and transmission capacity.[74] Hotter temperatures will lower generation efficiency and thus will require more energy to deliver the same amount of electricity. For example, solar panels have lower performance at temperatures that are above their tested temperature (25 degrees) due to interactions between temperature and semiconductor properties.[75] Natural gas

Figure B-1. Projected Temperature Change by 2100 Under National Climate Assessment Lower and Higher Emission Scenarios



Source:

Figure 6.7 from U.S. Global Change Research Program (USGCRP), "4th National Climate Assessment: Volume 1", 2017. Available at: https://science2017.globalchange.gov/.

* For ease of comparison, we have converted the values in this framework from Fahrenheit to Celsius. Original values are 1.3 to 1.7 degrees F.

† 3 to 4 degrees F

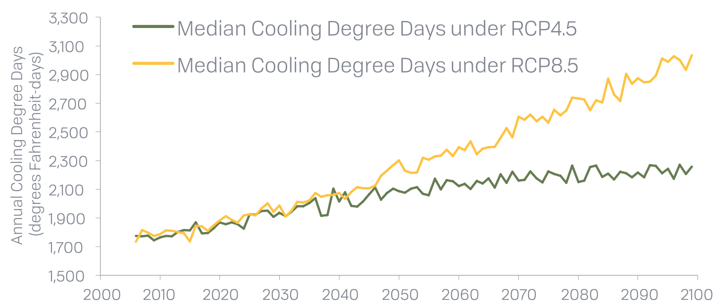
‡ 5 to 10 degrees F

combined cycle plant efficiency declines at a rate of 0.3 to 0.5 percent per degree above 15 degrees due to air density, air pressure, and temperature differentials.[76] One study found that under less optimistic emissions scenarios, higher temperatures during late summer months in California could cut natural gas generating capacity by three to six percent.[77] Similarly, large scale thermoelectric plants such as coal and nuclear have reduced power output at higher temperatures. Coal and nuclear generators that use surface water for cooling will be impacted by rising surface water temperatures, which reduces the efficiency of cooling systems and could force generation curtailment in order to avoid exceeding thermal discharge limits.[78, 79, 80] Finally, high temperatures can lead to greater losses during transmission. Under a high emissions scenario, California's transmission capacity is estimated to decline by seven to eight percent by 2100.[81] While these changes may not be dramatic at a plant or local system level, when aggregated over a region or over the entire U.S., efficiency and generation losses due to higher temperature have large effects. For example, a reduction of one percent in electricity generated by thermal power plants would equate to a loss of electricity generation consumed by three million Americans.[82]

Furthermore, changes in temperature and increased extreme weather events will increase peak summer electricity demand, due to greater load for air conditioning.* A study conducted by the Northwest Power Planning and Conservation Council found that climate change would result in a 1,000 MW increase in average monthly load in summer months. When factoring in peak demand during extreme events, summer peak demand would rise by 3,000 MW.[83] Similarly, a study conducted by the California Public Utilities Commission found that extreme heat could increase peak demand by as much as 21 percent under a high emissions scenario by end of century.[84] When coupled with diminished generation capacity due to efficiency losses and forced curtailments, this study found that California would need to bolster generation capacity by 38.5 percent.[85] Overall, total U.S. electricity demand is projected to grow by 1.5 to 6.5 percent by 2050 against a reference case with no climate-associated temperature increase.[86]

Tools that could assist businesses in this evaluation include the Climate Explorer, developed by the U.S. Climate Resilience Toolkit. This resource provides maps and data on projected daily temperatures, temperature extremes, precipitation, heating degree days, and cooling degree days through 2100 for all counties in the United States.† It includes projections for IPCC's warmer temperature scenarios, which project warming of 2.3-2.9 degrees and 4.1-4.8 degrees.‡ The data is downscaled to a resolution of 0.5 miles per pixel. **Figure B-2** displays the change in cooling degree days projected for Houston under these higher warming scenarios through 2100. It is possible to extract similar data for other counties and cities from the Climate Explorer.

Figure B-2.: Cooling Degree Days for Houston, Texas, Under Two Climate Change Scenarios



Source:

MJB&A Analysis.

U.S. Climate Resilience Toolkit, "The Climate Explorer," USGCRP, online at: https://toolkit.climate.gov/climate-explorer2/.

Similarly, the Climate Mapper tool provides climate projections, including temperature, humidity, precipitation and agricultural conditions for various IPCC cases at a resolution of 2.5 miles.** Other tools allow users to extract climate data for specific variables and scenario runs. For instance, the World Climate Research Programme's "Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections" project allows users to select regions, specific model runs, and emissions projection scenarios across the contiguous United States at a resolution of 3.7 miles.[87, ††] The 3rd U.S. NCA

* A warmer climate will decrease demand in winter months but as electricity demand for cooling is more concentrated in the electricity sector than demand for heat, summer months have higher electricity demand. Extreme heat events could increase total system peak demand to the point of necessitating additional peaking capacity.

† See, U.S. Climate Resilience Toolkit, "The Climate Explorer," USGCRP, online at: https://toolkit.climate.gov/climate-explorer2/.

‡ 4.1-5.2 degrees Fahrenheit and 7.4-8.6 degrees Fahrenheit, respectively.

** Specifically, the Representative Concentration Pathways (RCP) 4.5 and RCP8.5 cases. Available at: https://climate.northwestknowledge.net/MACA/

†† The objective of the Coupled Model Intercomparison Project (CMIP) is to better understand past, present and future climate changes arising from natural, unforced variability or in response to changes in radiative forcing in a multi-model context.

also produced state-level summaries for its two central emissions trajectories.[88] Finally, the United States is currently in the process of developing the second volume of the 4th NCA, which is slated to be released in mid-2018. This volume of the 4th NCA will have several new model runs and data, which should help companies determine the projected impacts of climate change under multiple scenarios.

Water Availability and Precipitation Patterns

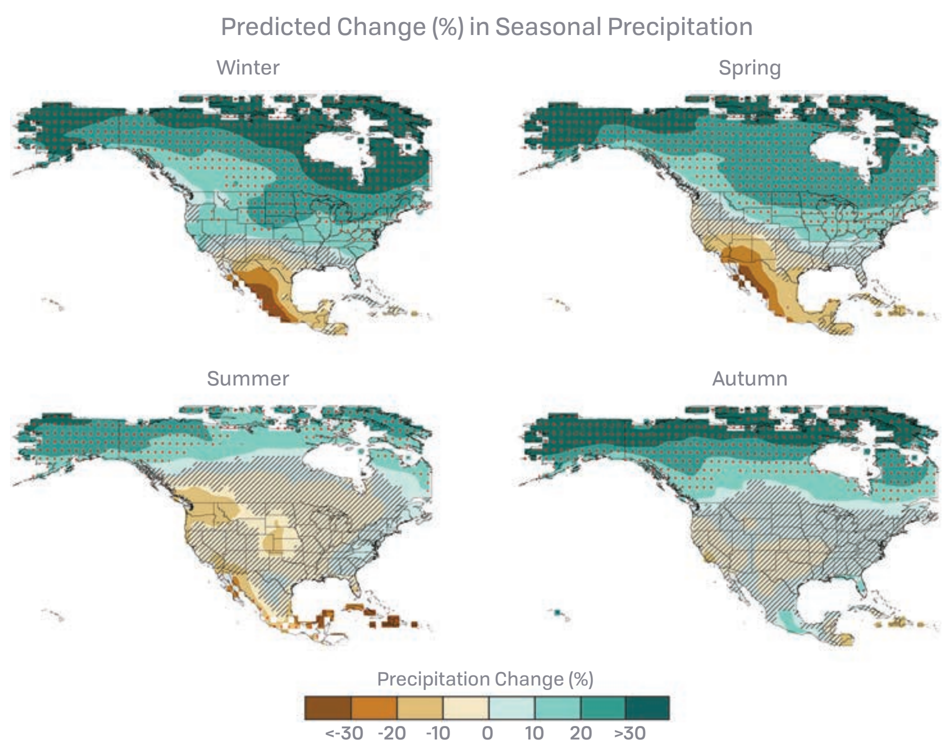
Changing precipitation patterns and resultant water availability changes are expected due to climate change; however, the magnitude and direction of the impact varies by region and by season (**Figure B-3**). For example, the Northeast is projected to see greater amounts of precipitation, while the Southwest will likely see a decline.[89] Under a high emissions scenario, annual precipitation in the Southwest during the winter and spring months is projected to decline by as much as 20 to 30 percent[90] with snow pack declining by up to 40 percent in these areas.[91] These months correspond to the periods that the Southwest receives most of its precipitation and snowpack, the latter of which is a critical reservoir for year-round water supply.[92] The Southwest, which has already faced record droughts and wildfires in recent years will become drier and more susceptible to these impacts.[93]

Furthermore, shifts in winter snowpack accumulation and the pace at which it melts throughout the season will also affect water availability during dry months.

Companies should consider how changes in water availability may impact generation capacity, particularly for companies in the electric power industry located in the Southeast and Southwest. Additionally, companies with a large share of their generating capacity in coal, nuclear, and hydroelectric assets should consider how strained water availability may impact generation capacity. Growing populations, competition for other water uses, and existing water scarcity will compound the strains imposed by climate change. Water shortages can also lead to greater draw-down of groundwater, which can cause the collapse of underground structures leading to subsidence of ground surfaces, creating structural issues for energy infrastructure. Alternatively, in areas that expect higher precipitation levels, companies should consider how increased precipitation could affect the stability of groundmass and any risks to electric grid or generating infrastructure.

In developing climate-related assessments, projected hydrologic data could be overlaid with current understanding of water demand, water use, water scarcity, and impacts to groundwater and runoff to

Figure B-3. Predicted Precipitation Range Under High Emissions Scenario (RCP 8.5)

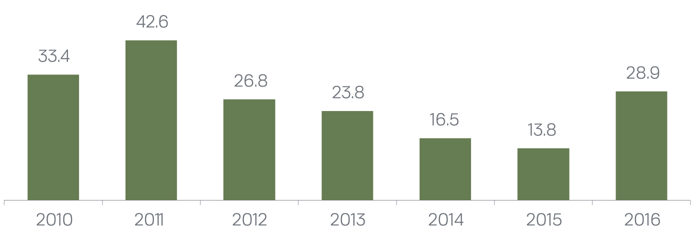


Source:

Figure 7.5 from U.S. Global Change Research Program (USGCRP), "4th National Climate Assessment: Volume 1", 2017. Available at: https://science2017.globalchange.gov/.

estimate the extent to changes in water availability will impact electric generation. For example, companies operating in California, which obtains a sizable share of generation from hydroelectric resources, could consider how decreased water availability could affect generation output. Recent data show that this risk could be significant — extended drought and reduced snowpack in 2014 and 2015 reduced California's hydroelectric generation by 70 percent from 2011 levels (**Figure B-4**).[94]

Figure B-4. Hydroelectric Generation in California (TWh)



Sources:

MJB&A Analysis.

California Energy Commission, "California Hydroelectric Statistics and Data — Total Hydroelectricity Production", February 20, 2018. Available at: http://www.energy.ca.gov/almanac/renewables_data/hydro/.

EIA, "Electrical Data Browser — Net Generation from Hydroelectric (conventional power) by state", February 20, 2018. Available at: https://www.eia.gov/electricity/data/browser/.

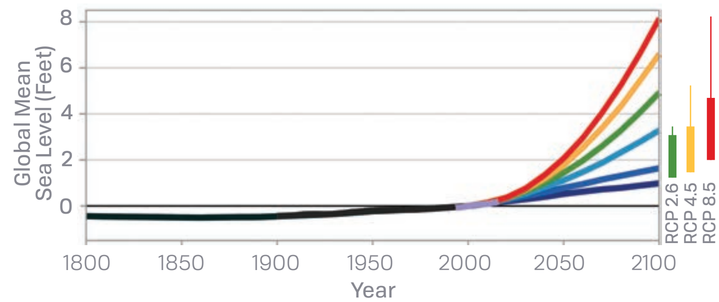
Useful tools that provide detailed hydrologic cycle projections under multiple emissions scenarios include the Climate Explorer,[95] Climate Mapper, and "Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections."[96]

Sea Level Rise

According to the 4th NCA, since 1900, global sea levels have risen by about eight inches and are projected to rise an additional four to seven inches by 2030, six inches to two feet by 2050 and one foot to eight feet by 2100 (**Figure B-5**).[97] Other studies have estimated sea levels reaching two feet by 2050 (Scripps) or by 2100 (DOE).[98] Nearly five million people in the U.S. live in areas that are within 4 feet of high-tide levels, meaning that under higher emissions scenarios, these communities would be inundated, even without accounting for flooding due to storm surge (discussed in more detail below).[99]

Energy sector facilities are particularly vulnerable to the impacts of sea level rise given their proximity to coasts,

Figure B-5. Projected Sea Level Rise under Emissions Scenarios



Sources:

Figure 12.4a from U.S. Global Change Research Program (USGCRP), "4th National Climate Assessment: Volume 1", 2017. Available at: https://science2017.globalchange.gov/.

and companies should consider their exposure to coastal inundation. This can be done by layering maps of existing assets on projected sea level rise data. A substantial amount of analysis has already been done in this space. A study of California power plants assessed the vulnerability of power plants to sea level rise and found that 25 plants in California are at risk of inundation with a four and a half feet sea level rise coupled with a 100-year flood.[100] While in the case highlighted above, these plants would likely have already reached retirement, there are other assets that are vulnerable even with modest increases in sea levels in the near term. Specifically, the 4th NCA notes that nuisance floods, corresponding with tidal peaks, have increased five- to ten-fold since the 1960s.[101] Furthermore, it is important to consider future flood risk when planning for new infrastructure investments.

DOE created a tool that analyzes the impact of sea level rise on energy assets for 10 major metropolitan cities at both a one-foot and four-foot rise.[102] It shows that by 2100 under a four-foot sea level rise scenario, New York City would have six substations and three power plants that would be exposed to inundation. With a six-foot rise by 2100, seven substations and one power plant in greater New Orleans would be at risk.[103]

NOAA's Sea Level Rise Viewer provides detailed sea level rise GIS data at various warming scenarios and at different benchmarks through the century.* This data is in a format that could be readily overlaid with company specific maps of generation assets, transmission lines, and substations to determine which assets would be at risk.

* See, NOAA Office of Coastal Management, "DigitalCoast — Sea Level Rise Viewer". Available at: https://coast.noaa.gov/digitalcoast/tools/slr.

Extreme Precipitation Events, Tropical Storms, and Coastal Storm Surge

Climate change will increase the frequency and intensity of storms, heavy downpours, and flooding. These can include both inland flooding and storm events as well as hurricanes.[104] Since the 1980s, Atlantic hurricane activity has increased and the frequency and intensity of tropical storms are projected to rise due to warmer tropical ocean temperatures associated with climate change.[105] In 2012, Hurricane Sandy hit the East Coast of the U.S., bringing with it 80-mile per hour winds and record storm surges. Seven years prior to that, Hurricanes Katrina and Rita ran through the Gulf Coast causing severe damage to oil and gas production. In 2017, the U.S. witnessed one of the most active hurricane seasons on record with four hurricanes landing on American soil. Hurricane Harvey unleashed 50 inches of rain outside of Houston, a record for the most rain from one storm. In the weeks that followed, Hurricane Irma, the strongest storm on record, devastated Caribbean islands before making landfall in Florida, and Hurricane Maria hit Puerto Rico as a category 5 hurricane wiping out the entire electric grid and water supplies.

Each of these storms caused billions of dollars in damages to communities but also damaged energy assets, power plants, and transmission lines. An additional key risk of hurricanes is storm surge, wherein an advancing hurricane creates a local and temporary significant rise in sea levels. Storm surge will be significantly exacerbated by sea level rise.[106] Together, these extreme weather events can result in severe damages and outages to the electric grid by inundating generating resources and substations and downing tree limbs and transmission and distribution lines. One study of the Delaware Valley found that 79 substations are currently be exposed to moderate flooding (mostly below 5 feet) from a category 3 hurricane; by 2050, with a warming climate, the same storm would threaten 84 substations, with a third of the substations exposed to water more than 15 feet deep.[107]

DOE's Electric Sector Vulnerability of Climate Change Report[108] and its guide to resilience planning[109] detail these impacts further. DOE and EEI have documented actions energy sector companies are already taking to increase their resiliency to hurricane and storm surge events.[110] These actions include, among others, strengthening floodwalls; relocating generation assets; increasing resilience of transmission lines and power plants to high winds; burying transmission lines; deploying advanced generation technologies such as distributed resources and batteries; and conducting readiness training. The DOE tool analyzing the impact of sea level rise also included an assessment of inundation associated with storm surge during a Category 1 and Category 3 hurricane.[111] EPA's Storm Surge Inundation and Hurricane Strike Frequency Map can assist companies in the electric power industry determine exposure to storm surge risk.*

* See, EPA, "Storm Surge Inundation Map". Available at: https://toolkit.climate.gov/tool/storm-surge-inundation-and-hurricane-strike-frequency-map.

Climate change can also increase inland intense precipitation events and storms, which can cause local flooding, downed infrastructure from severe winds, and other impacts. The 4th NCA estimates that extreme daily precipitation events will increase by 25 percent across the United States by 2100 under a high emission scenario.† In 2012, a superstorm known as a derecho brought intense thunderstorms and high winds to the Mid-Atlantic region that left four million people and businesses without power, some for more than a week, and caused millions of dollars in property damages.[112] Flooding is a particular risk for many energy assets located along river beds or in low-lying areas, including rail systems used for transporting coal. In 2011, flooding in the Powder River Basin disrupted these transportation routes delaying of coal deliveries and leading to millions in incurred costs.[113] Companies should thus pay special attention to assets, including transmission lines and fuel supply lines that are in floodplains.

Wildfires

High temperatures and prolonged periods of drought are expected to lead to more frequent and intense wildfire events in the future, particularly in western forests.[114] The U.S. Forest Service notes that "projected higher summer temperatures will likely increase the annual window of high fire risk by 10-30%."[115] Already the wildfire season in the U.S. has grown by 80 days since 1980.[116]

Wildfires pose a threat to transmission lines. In the coming decades, wildfires are expected to lead to greater maintenance costs for companies in the electric power industry and decreased line capacity.[117] Companies should consider in climate-related assessments how transmission outages and increased maintenance costs would affect their business. The California Energy Commission quantified the risk of wildfire on transmission and its report is a helpful resource for assessing potential risks of wildfire to operations.[118]

Changes in Wind Patterns

Beyond the damages of higher wind speeds during extreme weather events (e.g., thunderstorms, tropical storms, ice storms), climate change is projected to alter wind speeds and wind patterns, which could affect wind generation.[119] Overall, climate models vary widely in projected average wind speeds depending on their emissions trajectories, making planning for anticipated changes difficult. The Climate Mapper tool provides projected changes in seasonal wind speeds down to a resolution of 2.5 miles.[120] The tool shows that under lower emissions scenarios, wind speeds are projected to decline across most of the U.S. through the end of century, with Wyoming and parts of Ohio experiencing the largest declines in wind speed (as high as 0.5-1.2 miles per hour). However, in higher emissions scenarios, wind speeds increase in southern and eastern Texas by end of century.[121] While there is a need for continued research in this area, decreases and increases in annual and seasonal wind speed could impact electric power industry assets.

Wildfires pose the greatest threat to transmission lines. In the coming decades, wildfires are expected to lead to greater maintenance costs for companies in the electric power industry and decreased line capacity. Companies should consider in climate-related assessments how transmission outages and increased maintenance costs would affect their business.

† In this section, extreme precipitation events is defined as the number of days with precipitation that exceeds the 95th percentile of all non-zero precipitation days.

APPENDIX C: ADDITIONAL RESOURCES

1. Cimate-Related Disclosure and Scenario Analysis

McKinsey and Company

- "From scenario planning to stress testing: The next step for energy companies": http://www.mckinsey.com/business-functions/risk/our-insights/from-scenario-planning-to-stress-testing-the-next-step-for-energy-companies
- "Overcoming obstacles to effective scenario planning": https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/overcoming-obstacles-to-effective-scenario-planning

Task Force for Climate-Related Financial Disclosures

- Final Recommendations: https://www.fsb-tcfd.org/publications/final-recommendations-report/
- Annex I: Implementing the Recommendations: https://www.fsb-tcfd.org/publications/final-implementing-tcfd-recommendations/
- Technical Supplement: The Use of Scenario Analysis in Disclosure of Climate-related Risks and Opportunities: https://www.fsb-tcfd.org/publications/final-technical-supplement/

World Economic Forum

- "Global Risks Report 2018": http://reports.weforum.org/global-risks-2018/global-risks-landscape-2018/#landscape

2. 2-Degree Transition Resources

2 Degree Investing Initiative

- "Transition Risk Toolbox – Scenarios, Data and Models": http://2degrees-investing.org/IMG/pdf/2ii_et_toolbox_v0.pdf

MIT Center for Energy and Environmental Policy Research

- "Energy Scenarios: The values and limits of scenario analysis" http://ceepr.mit.edu/files/papers/2016-007.pdf

3. 2-Degree Transition Scenarios

Deep Decarbonization Pathways Project

- "Pathways to Deep Decarbonization in the United States": http://deepdecarbonization.org/countries/#united-states

Energy Modeling Forum – 24

- "Study on U.S. Technology and Climate Policy Strategies:" https://web.stanford.edu/group/emf-research/docs/emf24/EMF_24.pdf

International Energy Agency

- IEA 2017 WEO: https://www.iea.org/weo2017/
- IEA 2016 WEO: https://www.iea.org/newsroom/news/2016/november/world-energy-outlook-2016.html
- IEA 2017 Perspectives for the Energy Transition: https://www.iea.org/publications/insights/insightpublications/PerspectivesfortheEnergyTransition.pdf

Natural Resources Defense Council

- "America's Clean Energy Frontier: The Pathway to a Safer Climate Future": https://www.nrdc.org/sites/default/files/americas-clean-energy-frontier-report.pdf

Pacific Northwest National Laboratory

- "GCAM-USA Analysis of U.S. Electric Power Sector Transitions": https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-26174.pdf

U.S. Mid-Century Strategy for Deep Decarbonization

- Final Report: http://unfccc.int/files/focus/long-term_strategies/application/pdf/mid_century_strategy_report-final_red.pdf
- Documentation and Output Data: http://unfccc.int/files/focus/long term_strategies/application/pdf/us_mcs_documentation_and_output.pdf

4. Other Energy Sector Projections

U.S. Energy Information Administration

- "Annual Energy Outlook": https://www.eia.gov/outlooks/aeo/

5. Oil and Gas Specific Transition Risk Reports

Ceres

- "A Framework for 2 Degrees Scenario Analysis: A Guide for Oil and Gas Companies and Investors for Navigating the Energy Transition": https://www.ceres.org/sites/default/files/reports/2017-03/Framework_Jan%2010%2017.pdf
- "Investor Climate Compass: Oil and Gas": https://www.ceres.org/sites/default/files/reports/2017-05/IIGCC%202017%20Oil%20and%20Gas%20Investor%20Expectations%20v42.pdf

6. Physical Risk Resources and Overviews

Boston, Massachusetts

- "Climate Ready Boston" https://www.boston.gov/departments/environment/climate-ready-boston

California Public Utilities Commission

- "Climate Adaptation in the Electric Sector: Vulnerability Assessments and Resiliency Plans": http://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/About_Us/Organization/Divisions/Policy_and_Planning/PPD_Work/PPD_Work_Products_(2014_forward)/PPD%20-%20Climate%20Adaptation%20Plans.pdf

Edison Electric Institute

- "Before and After the Storm: A complication of recent studies, programs and policies related to storm hardening and resiliency": http://www.eei.org/issuesandpolicy/electricreliability/mutualassistance/Documents/BeforeandAftertheStorm.pdf

Intergovernmental Panel on Climate Change

- "Fifth Assessment Report Working Group I Report — Climate Change 2013: The Physical Science Basis": http://ipcc.ch/report/ar5/wg1/
- "Fifth Assessment Report Working Group II Report — Climate Change 2014: Impacts, Adaptation and Vulnerability": http://ipcc.ch/report/ar5/wg2/
- "Fifth Assessment Report Climate Change 2014: Synthesis Report" http://ipcc.ch/report/ar5/syr/

New York City

- "A Stronger More Resilient New York" http://www.nyc.gov/html/sirr/downloads/pdf/final_report/Ch_6_Utilities_FINAL_singles.pdf

U.S. Department of Energy

- "Climate Change and the Electricity Sector: Guide for Climate Change Resilience Planning": https://energy.gov/sites/prod/files/2016/10/f33/Climate%20Change%20and%20the%20Electricity%20Sector%20Guide%20for%20Climate%20Change%20Resilience%20Planning%20September%202016_0.pdf
- "U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather": https://energy.gov/sites/prod/files/2013/07/f2/20130716-Energy%20Sector%20Vulnerabilities%20Report.pdf
- "Partnership for Energy Sector Climate Resilience": https://energy.gov/policy/initiatives/partnership-energy-sector-climate-resilience
- "A Review of Climate Change Vulnerability Assessments: Current Practices and Lessons Learned from DOE's Partnership for Energy Sector Climate Resilience": https://www.energy.gov/sites/prod/files/2016/10/f33/A%20Review%20of%20Climate%20Change%20Vulnerability%20Assessments%20Current%20Practices%20and%20Lessons%20Learned%20from%20DOEs%20Partnership%20for%20Energy%20Sector%20Climate%20Resilience.pdf
- "Hardening and Resiliency: U.S. Energy Industry Response to Recent Hurricane Seasons":http://www.oe.netl.doe.gov/docs/HR-Report-final-081710.pdf

U.S. Global Change Research Program

- "3rd National Climate Assessment": http://nca2014.globalchange.gov/
- "3rd National Climate Assessment State Summaries": https://statesummaries.ncics.org/
- Down-scaled and localized projections: https://scenarios.globalchange.gov/
- "4th National Climate Assessment Volume I — Climate Science Special Report": https://science2017.globalchange.gov/

7. Physical Risk Tools and Databases

Cal-Adapt

- "Exploring California's Climate Change Research": http://cal-adapt.org/

Lawrence Livermore National Laboratory

- "Coupled Model Inter-comparison Project Phase 5": http://cmip-pcmdi.llnl.gov/cmip5/

National Center for Atmospheric Research

- "Climate Change Scenarios GIS data portal": https://gisclimatechange.ucar.edu/inspector

U.S. Department of Energy

- "Sea Level Rise and Storm Surge Effects on Energy Assets": https://icfgeospatial.maps.arcgis.com/apps/MapSeries/index.html?appid=58f90c5a5b5f4f94aaff93211c45e4ec

U.S. Environmental Protection Agency

- "Climate Assessment Tool": https://www.epa.gov/exposure-assessment-models/basins-climate-assessment-tool-tutorials

U.S. Global Change Research Program

- "Climate Resilience Toolkit": https://toolkit.climate.gov/

U.S. National Oceanic and Atmospheric Administration

- "Sea Level Rise Viewer": https://coast.noaa.gov/digitalcoast/tools/slr

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2 M.J. Bradley & Associates, “Powering America: The Economic and Workforce Contributions of the U.S. Electric Power Industry”, August 2, 2017. Available at: https://mjbradley.com/sites/default/files/PoweringAmerica.pdf.

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4 Financial Security Board Task Force on Climate-Relate Financial Disclosures (TCFD), “Final Report: Recommendations of the Task Force on Climate-Related Financial Disclosures”, June 29, 2017. Available at: https://www.fsb-tcfd.org/publications/final-recommendations-report/.

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