NIAC The President's National Infrastructure Advisory Council

Managing the Infrastructure Challenges of Increasing Electrification

December 2023

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About the NIAC

The President's National Infrastructure Advisory Council (NIAC or the Council) is composed of senior executives from industry and state and local government who own and operate the critical infrastructure essential to modern life. The Council was established by executive order in October 2001 to advise the President on practical strategies for industry and government to reduce complex risks to the designated critical infrastructure sectors.

At the President's request, NIAC members conduct in-depth studies on physical and cyber risks to critical infrastructure and recommend solutions that reduce risks and improve security and resilience. Members draw upon their deep experience, engage national experts, and conduct extensive research to discern the key insights that lead to practical Federal solutions to complex problems.

For more information on the NIAC and its work, please visit: https://www.cisa.gov/niac.

1. Executive Summary

Electricity is an essential factor in many everyday tasks in American life. The trend toward increasing electricity is most evident in the growing number of electric vehicles (EV) on the road, but it is also occurring in buildings, where more and more functions like heating and cooking are being converted from furnaces to heat pumps and from gas burners to induction coils. Electrification trends are being driven by technological innovation, favorable economics for the end user, consumer preferences, policy support, and utility incentives. While the electrification trend has the potential to provide energy and cost savings, cleaner air, greenhouse gas reductions, and performance benefits, electrification also presents challenges and risks to national infrastructure sectors, including, significantly, the electric power sector. If not addressed with thoughtful foresight and coordination, these challenges could have significant impacts resulting in decreased reliability and increased costs.

Electrification is one of the strategies used in Federal policies to manage United States (U.S.) climate change risk exposure, which is a national security issue with increasing geopolitical urgency. The focus on electrification aligns with a wider reassessment of the grid's needs in the service of its many energy users. Electrical infrastructure is often exposed to the elements and, by extension, to many aspects of increased climate risk. Extreme weather events like wildfires, hurricanes, derecho winds, extreme heat, and extreme cold have a direct impact on the grid and on all communities that depend on reliable power. Given the need to plan the climate adaptation of grid infrastructure to both immediate- and long-term impacts, infrastructure planning must be able to encompass changing grid uses to ensure that grid modernization projects are developed affordably and quickly. Grid infrastructure, including the portfolio of demand responsive and resilient technologies, is a key public resource facilitating social benefits and economic prosperity: benefits that are best secured with foresight. Indeed, the need to look toward the future is underscored by the challenges that we face in the present.

Recently, several states have experienced complete or significant losses of the electrical system due to extreme weather and/or public safety power shut offs to reduce the risk of fires. These events underscore the importance of pursuing electrification to mitigate severe climate risk while demonstrating the work that needs to be done to improve brittle infrastructure and design for resilience. Decarbonization through mass electrification is one of the defining challenges of our time due to climate risk mitigation and adaptation.

This report outlines the challenges facing five critical infrastructure sectors when increasing electrification. The NIAC proposes eleven recommendations to mitigate the challenges:

1. Endorse a state and Federal, equity-centered "reliability forward" electrification strategy. Require that policies and regulations on electrification are paired with adequate planning and investment in the reliable supply, delivery, and storage of power to ensure that grid capacity development in generation, transmission, and distribution precedes electrification demand for all communities.
2. Establish a multi-sectoral Federal resilience framework with state regulatory participation that guides the deployment of advanced planning and modeling tools. It would provide inclusive, consistent, and objective input on capacity planning, project prioritization, location-specific resilience to climate emergencies, and targeted resilience strategies to address community and business needs.
3. Actively address supply chain issues through policy in the electrical equipment sector and plan to establish a strategic reserve of key electrical equipment.
4. Develop a roadmap for efficient electrical transportation and transportation energy distribution infrastructure.

5. Build advanced research and development (R&D) support for industrial electrification by establishing technology demonstration partnerships between the Department of Energy (DOE), candidates for industrial electrification, and local distribution utilities. In turn, these planning initiatives and collaborations with utilities can ensure that significant new loads are adequately accounted for in system planning and grid impact studies.
6. Advance education policy initiatives that support workforce development and energy stewardship as key professional and civic competencies for both new and tenured employees. This would begin to address the steep learning curve for electrification technologies.
7. Conduct a national cybersecurity assessment of software, hardware, network, distribution, and generation, to be led by the Office of Cybersecurity, Energy Security, and Emergency Response at the Department of Energy (DOE), with the assistance of the private sector and intelligence agencies tasked with preventing attacks by foreign states.
8. Establish a taskforce to identify barriers to multi-state transmission project success. This would, potentially, advance policy-enabling projects across political boundaries in deregulated and regulated markets and to weave together disparate power grids.
9. Convene an inter-agency taskforce to advance standards for control systems as well as physical and cybersecurity to ensure interoperability and data exchange, enabling the resilience potential of distributed energy resources (DER) and controllable loads.
10. Given the significant variation in state-level policy and the need for coordination with Federal regulators and policymakers that may hinder the standardization of electrification tools, technologies, and markets, convene a joint working group to incentivize policy harmonization that aligns with both international standardization efforts and state-level initiatives.
11. Strengthen standards for emergency response information-sharing and coordination between power utilities and Federal, state, local, territorial, and tribal governments for preparedness, response, recovery, and mitigation of power disruptions.

2. Introduction

2.1. The NIAC's Charge

On December 27, 2022, the National Security Council (NSC) tasked the NIAC to investigate the following question:

> *What are the most significant risks to security and resilience of our Nation's infrastructure posed by electrification, and what actions should the Federal government and infrastructure owners and operators take to manage those risks?*[1]

The Electrification Subcommittee was established to undertake this task. The Subcommittee consisted of twenty members; a full list of whom can be found in Appendix B. Gil Quiniones was designated as the Subcommittee Chair.

The NSC provided further guidance to the Subcommittee to focus its efforts on five of the critical infrastructure sectors among those designated by CISA. The five focus sectors include the following:

- energy;
- transportation;
- communications;
- financial services; and
- critical manufacturing.

Additionally, the NSC encouraged the Subcommittee to consider the impacts at the community level that electrification may have so communities may adequately prepare.

2.2. Subcommittee Activities

The Subcommittee held meetings on the following dates:

March 20, 2023 – Kickoff meeting for the Subcommittee.

April 5, 2023 – Subcommittee meeting focused on the impacts on the electrical power sector and featured briefings from: Scott Aaronson, Senior Vice President, Edison Electric Institute; Emanuel Bernabeu, Senior Director, Applied Innovation and Analysis, PJM Interconnection; and Arshad Mansoor, CEO, Electric Power Research Institute.

April 14, 2023 – Subcommittee meeting focused on state and regional electricity policy perspectives and featured briefings from: Jim Robb, President and CEO, North American Electric Reliability Corporation and David Terry, President, National Association of State Energy Officials.

April 19, 2023 – Subcommittee meeting focused on discussing feedback on speaker briefings and sectors for additional focus.

May 10, 2023 – Subcommittee meeting discussed perspectives on transportation and building electrification and featured briefings from McKinsey & Company Partners and Associate Partner, Shivika Sahdev, Evan Polymeneas, and Ann Hewitt, respectively.

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[1] For the purpose of this study, "electrification" is defined as the transition from fossil-fuel based energy sources to electricity as a source of energy.

May 23, 2023 – Subcommittee meeting discussed perspectives on grid-edge technologies and featured briefings from: Arch Rao, Founder and CEO, Span IO; Prasanna Venkatesan, Executive Vice President and Head of Strategy Landis & Gyr; Jesse Morris, CEO, Energy Web Foundation; and Leia Guccione, Managing Director, Rocky Mountain Institute.

June 2, 2023 – Subcommittee meeting featured briefings from the White House Office of Science and Technology Policy: Costas Samaras, Principal Assistant Director for Energy and Chief Advisor for Energy Policy and Tom Wilson, Assistant Director for Electricity.

June 20, 2023 – Subcommittee meeting focused on electrification of heavy transportation and featured briefings from: Ian Gansler, Manager of Energy, Resilience, and Sustainability Policy, American Association of Port Authorities and Sean Conboy, Energy Manager, Denver International Airport.

July 6, 2023 – Subcommittee meeting focused on electrification of light transportation and featured briefings from: Cris Liban, Chief Sustainability Officer, Los Angeles County Metropolitan Transportation Authority; Pasquale Romano, President and CEO, ChargePoint; and Teza Mukkavilli, Chief Information Security Officer, ChargePoint.

July 21, 2023 – Subcommittee meeting featured briefings from Eric Rollison, Assistant Director, Office of Cybersecurity, Energy Security and Emergency Response, DOE, and Sadek Wahba, Managing Partner, I Squared Capital.

August 3, 2023 – Subcommittee meeting featured briefings from the National Renewable Energy Laboratory: Juan Torres, Associate Laboratory Director, Energy Systems Integration; Jacquelin Cochran, Director, Grid Planning and Analysis Center; and Trieu Mai, Distinguished Member of the Research Staff, Model Engineering.

August 16, 2023 – Subcommittee meeting featured a briefing from Joseph McClelland, Director, Office of Energy Infrastructure Security, Federal Energy Regulatory Commissions (FERC).

September 1, 2023 – Subcommittee meeting featured a briefing about the views of the National Association of Regulatory Utility Commissioners (NARUC) led by Andrew Fay, Florida Public Service Commissioner.

October 26, 2023 – Subcommittee meeting featured a discussion with members of the National Economic Council White House Office and the White House Office of Science and Technology Policy.

October 31, 2023 – Subcommittee meeting featured a discussion with members of the White House Office of Climate Policy, the White House Office of Clean Energy Innovation and Implementation, and the White House Office of Infrastructure Implementation.

2.3. Organization of this Report

The remainder of this report is organized into the following three sections:

Trends and Opportunities in Electrification in the U.S. describes the drivers of increased electrification in the American economy and the magnitude of electrification impact that can be expected by 2050.

Impacts on Selected Critical Infrastructure Sectors details the impacts that U.S. infrastructure areas may experience with increasing electrification.

Recommendations provides the NIAC's suggestions for policy actions to harmonize policy objectives, increase coordination, and encourage greater resilience and recovery of critical infrastructure sectors, including, most importantly, the U.S. power grid.

3. Trends and Opportunities in Electrification

3.1. The Rise in Electrification

Reliance on electricity is on the rise. After years of roughly stable consumption, beginning with the 2009 recession through the present, the U.S. electricity load is now forecasted to grow by between 2% and 4% per year (depending on various scenarios for achieving net-zero emissions targets) (Figure 1). Currently, there is a pronounced shift towards electrification in the U.S. In fact, Electrification briefers described a future in which nearly all transit and building energy needs will be served by electricity, with a possibility of new industrial electrical demand increasing loads as well. The four factors outlined below drive this trend.

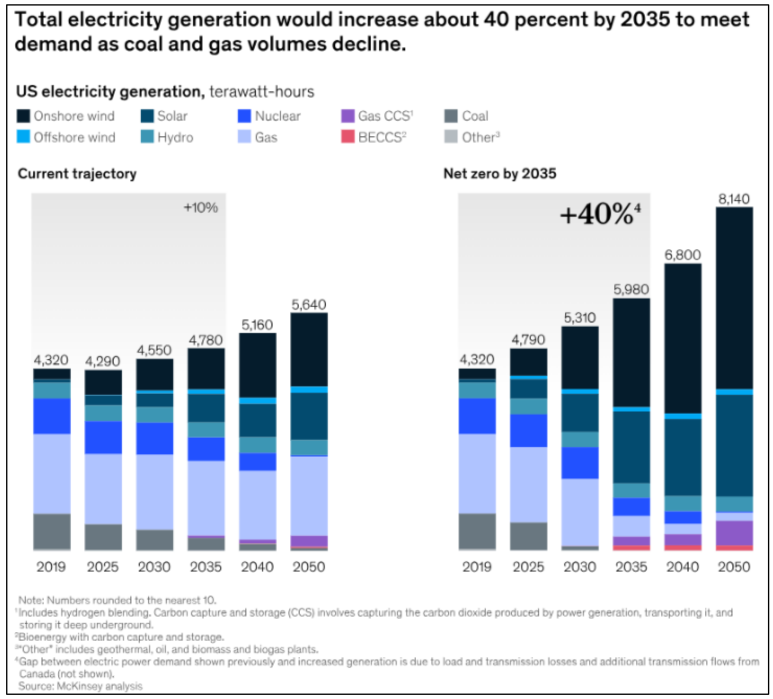

Figure 1: Total Electricity Generation Increase by 2035

3.1.1. Technical Innovation

Advancements in battery technology have spurred the popularity of EVs, improving vehicle range and efficiency to broaden the range of appropriate use cases for vehicles. In 2011, the median range of a passenger battery EV (BEV) was 68 miles. By 2020, that average had increased to 259 miles.[2] These innovations are informing improvements in light- and heavy-duty vehicles and buses. And those improvements have led to new applications such as grid energy storage, which is projected to increase by a factor of ten by 2035.[3] Similarly, heat pump adoption is soaring in the U.S. For example, Maine is a notably cold-weather winter environment where heat pumps traditionally have not been advantageous. Nevertheless, in 2023, the state surpassed its goal of installing 100,000 heat pumps two years ahead of schedule.[4]

3.1.2. Consumer Preferences and Cost Savings

In many instances, the electrified alternatives to conventional fossil fuel-powered cars and appliances are safer, quieter, healthier, and easier to use, making them increasingly popular with consumers. Electrification decisions – such as purchasing a BEV, heat pump, or induction cooktop – have traditionally been

[2] DOE Office of Energy Efficiency and Renewable Energy, "FOTW# 1167, January 4, 2021: Median Driving Range of All-Electric Vehicles Tops 250 Miles for Model Year 2020," Energy.gov, January 4, 2021, https://www.energy.gov/eere/vehicles/articles/fotw-1167-january-4-2021-median-driving-range-all-electric-vehicles-tops-250.
[3] Tony Lenoir and Aude Marjolin, "Charging up on Battery Energy Storage 101, US Market Outlook," www.spglobal.com, April 25, 2023, https://www.spglobal.com/marketintelligence/en/news-insights/research/charging-up-on-battery-energy-storage-101-us-market-outlook.
[4] Office of Governor Janet T. Mills, "After Maine Surpasses 100,000 Heat Pump Goal Two Years ahead of Schedule, Governor Mills Sets New, Ambitious Target | Office of Governor Janet T. Mills," www.maine.gov, July 21, 2023, https://www.maine.gov/governor/mills/news/after-maine-surpasses-100000-heat-pump-goal-two-years-ahead-schedule-governor-mills-sets-new.

complicated by the need to overcome higher upfront costs for technologies that have lower ongoing operating costs. However, incentives provided by the Inflation Reduction Act (IRA) and other policy measures work to offset the higher initial cost of choosing an electrified solution. After that point, consumers continue to benefit from lower operating costs of an electrified solution. The DOE estimated in 2022 that EV drivers pay $1.22 to drive the same distance that an internal combustion car can go on a gallon of gasoline. Gasoline prices are highly volatile, but assuming an average price of $3.00 per gallon offers substantial operational savings for the owner of an EV passenger vehicle.[5]

3.1.3. Corporate Policies and Investor Preferences

Increasingly, major public and private corporations are being pressed to demonstrate the decarbonization of their operations through a commitment to a low-carbon and low-emissions future. From investor disclosures to regulatory risks, carbon accounting and carbon accountability are on the rise. Of the 500 largest companies globally, 63% have already set a major climate milestone, and a quarter of these companies did so in 2022 alone.[6] Companies have strong incentives to embrace electrification policies that meet environmental, social, and governance objectives and deliver cost savings to maintain profitability. The two most accessible strategies for reducing direct fossil fuel consumption are increasing efficiency and adopting electric alternatives, with the second strategy depending, in turn, on the availability of clean generation to mitigate Scope 2 emissions.[7]

3.1.4. Policy Imperatives

In 2021, President Biden announced that the U.S. would aim to halve domestic greenhouse gas emissions by 2030 (relative to 2005 levels) and reach net-zero emissions by 2050 with the aim of limiting global warming to 1.5° Celsius. 2022's IRA provides $415 billion in total funding over 10 years in climate spending. These and other policy initiatives at the Federal and state levels are anticipated to spur significant investments in solar and wind generation, storage, and distribution capacity, as well as investment in home and building electrification.

3.2. Key Electrification Technologies

Electrification and, more precisely, beneficial electrification, involves replacing fossil fuel energy sources with electric alternatives to achieve improvements in efficiency, performance, cost, energy sovereignty, air quality, and greenhouse gas emissions. While electrification is expanding to achieve these benefits, key technical advancements also play a critical role by making electrification benefits attainable and affordable. Advancements in energy storage, heat pumps, and clean generation are promoting electrification.

Storage

Developments in mobile phone and laptop computer batteries led to an evolution in battery technologies that built a foundation for efficient, long-range EVs; the designs of which are now informing innovations in medium- and heavy-duty vehicles. In turn, demand for batteries in vehicles has fostered exploring additional

[5] Scott Minos, "Saving Money with Electric Vehicles," Energy.gov, September 28, 2022, https://www.energy.gov/energysaver/articles/saving-money-electric-vehicles.
[6] Climate Impact Partners, "Climate Commitments of the Fortune Global 500" https://www.climateimpact.com/news-insights/news/climate-impact-partners-releases-fourth-annual-report-climate-commitments-fortune-global-500/.
[7] Scope 2 emissions are emissions that a company causes indirectly via electrical consumption.

innovation in batteries to identify new materials that reduce cost and accelerate charging speeds and new applications, like grid energy storage.

Heat Pumps

Heating, ventilation, and air conditioning (HVAC) technologies are advancing to provide heat in buildings more efficiently across a wider range of temperatures. The advent of increasingly efficient HVAC technologies combined with advancements in energy efficient buildings allows for unprecedented levels of building performance and lower operating costs.

Clean Generation

With the rise of renewable energy and optimism for nuclear generation, a course is being charted toward a cleaner grid. Many organizations include grid pollution in their own carbon accounting inventories as Scope 2 emissions. With increases in the portion of total energy demand met by low-carbon generation, the benefits of electrification increase as well.

In recognition of the economic opportunities that arise from these technical innovations, a new wave of industrial policies is coming into effect that aims to diversify workforce participation to groups that have not previously participated in the clean energy transition and to onshore the production capacity of components such as batteries and solar panels. Doing so emphasizes the efficiency of electricity, and, where possible, leaving the hard-to-electrify end uses for higher-cost low-carbon fuels, such as green hydrogen and other hydrogen-derived fuels.

3.3. Electrification Efficiency

Across all electrification trends, efficiency and demand response stand apart as the two fundamental strategies to mitigate grid impact. These strategies not only reduce grid impact, but they also can lower total energy bills, which serves as a key justification for electrification. Electric alternatives can provide more efficient solutions than their combustion counterparts. In heat pumps, for example, a coefficient of performance (COP) of greater than three is common in equipment that is widely installed in residential applications (implying that a customer gets three units of energy output for every unit of energy input). By comparison, the most efficient heat exchanger on a natural gas furnace provides a COP of less than one.[8] In other words, heat pumps use electricity at least three times more efficiently than legacy gas furnaces.

In transportation, the well-to-wheel efficiency of a gasoline-powered vehicle is estimated to range from 12-30%, whereas BEVs transfer 77% of grid energy to the wheels.[9] Nevertheless, the efficiency benefits of electric alternatives are diminished under certain operating conditions, (e.g., during extremely hot or cold conditions) which limit the reliable and dispatchable generation or a significant campaign of energy efficiency. Further, relative to alternative decarbonization strategies like hydrogen and hydrogen-derived fuels, efficiency again favors electrification. To illustrate, the three largest mining companies in Australia – Broken Hill Proprietary (BHP), Rio Tinto, and Fortescue – have all announced their plans to electrify heavy-

[8] Though much less common than electric heat pumps, natural gas heat pumps have also been demonstrated with a COP of up to 1.9. See GTI, "Commercial gas heat pumps for hot water and A/C," Technical Summary of CEC PIR-16-001, January 6, 2021. https://www.gti.energy/wp-content/uploads/2021/03/WhitePaper-Commercial-Gas-Heat-Pumps-for-Hot-Water-AC-Demo-Restaurant-Applications_06Jan2021.pdf

[9] DOE Office of Energy Efficiency & Renewable Energy and EPA, "All-Electric Vehicles," Fueleconomy.gov, 2017, https://www.fueleconomy.gov/feg/evtech.shtml.

duty mining vehicles rather than utilizing hydrogen fuels because the EVs nearly triple the fuel-to-wheel efficiency compared with fuel cells.[10]

3.4. Electrification Case Studies and Major Policy Milestones

Regardless of what factors are driving the transition, the signs of ramping up for electrification are everywhere, so much so that key resource bases are struggling to keep up in the following areas:

- raw material markets, where critical minerals are the limiting factor for inputs to motors, batteries, and conductors;
- manufacturing, where production capacity is also a growth-limiting factor for outputs such as power transformers and batteries; and
- the consumer sector, where workforces are tooling up to install and service new equipment like EV charging sites.

In turn, these impacts are felt across the economy. Though constraints vary regionally, generation interconnection and project timelines for clean technology manufacturing projects are lengthening, which is more difficult to alleviate amidst supply chain disruption.

Despite these implementation challenges, the movement towards electrification is visible across residential, commercial, and industrial sectors, large scale projects are already underway, and several states and localities are advancing electrification agendas in their building codes.

Privately funded electrification initiatives are supported by substantial Federal and state incentives that are essential to de-risk new technologies and to accelerate the market availability of alternatives. Both the Infrastructure Investment and Jobs Act (IIJA) and the IRA have explicit electrification funding streams designed to accelerate transportation and building electrification. As these incentives roll out through Federal and state funding programs, they remove barriers to electrification by establishing charging networks and building workforce competencies that are essential to many adoption decisions for electric alternatives. Major program components include the following investments:

- A $5 billion allocation to the National Electric Vehicle Infrastructure (NEVI) Formula Program, including both charging network development, which will support interstate travel along designated alternative fuel corridors, and a broader public-charging deployment
- A $2.5 billion allocation to the Charging and Fueling Infrastructure Grants (CFI) supporting public-sector entities that install publicly accessible charging infrastructure
- A $4.3 billion allocation to the Home Electrification and Appliance Rebates Program that will help state energy offices support electrification in single-family and multifamily homes

[10] Polly Martin, "'More Economic and More Achievable' | Third Mining Giant Opts for Battery-Electric over Hydrogen in Its Vehicles," Hydrogen news and intelligence | Hydrogen Insight, June 26, 2023, https://www.hydrogeninsight.com/industrial/more-economic-and-more-achievable-third-mining-giant-opts-for-battery-electric-over-hydrogen-in-its-vehicles/2-1-1474582.

4. Impact of Electrification on Selected Critical Infrastructure Sectors

Despite electrification benefits, replacing fossil fuels with electric alternatives also presents significant risks. This section focuses on risks to the key sectors identified by the NSC.[11] The first and longest section focuses on the electric sector where electrification may impact both reliability and resilience, which will affect the other sectors. Subsequent sections address each of the sectors highlighted in the NSC guidance, and the final risk assessment concludes with an overview of additional social, political, and economic risk factors that define the complex community challenge of electrification. Together, these sections comprise key (but not exhaustive) components of a fundamental electrification risk assessment.

4.1. Electric Sector

4.1.1. Grid Reliability

The electrical grid is a complex and interdependent system that reduces the costs and constraints of a stand-alone power system. The grid's reliability lays the foundation for all other electrification efforts across other sectors. A briefer from the Edison Electric Institute described the electricity sector as the "apex sector" in which a failure would impact numerous critical infrastructure sectors. The DOE's Office of Cybersecurity, Energy Security, and Emergency Response presented the graphic shown in Figure 2 that demonstrates how the electricity sector is central to other critical infrastructure systems.

[11] This report emphasizes the impact of electrification on a limited number of sectors, but the impact of electrification efforts affects almost all critical infrastructure sectors. See Appendix 2 for a table summarizing the impact across all major sectors.

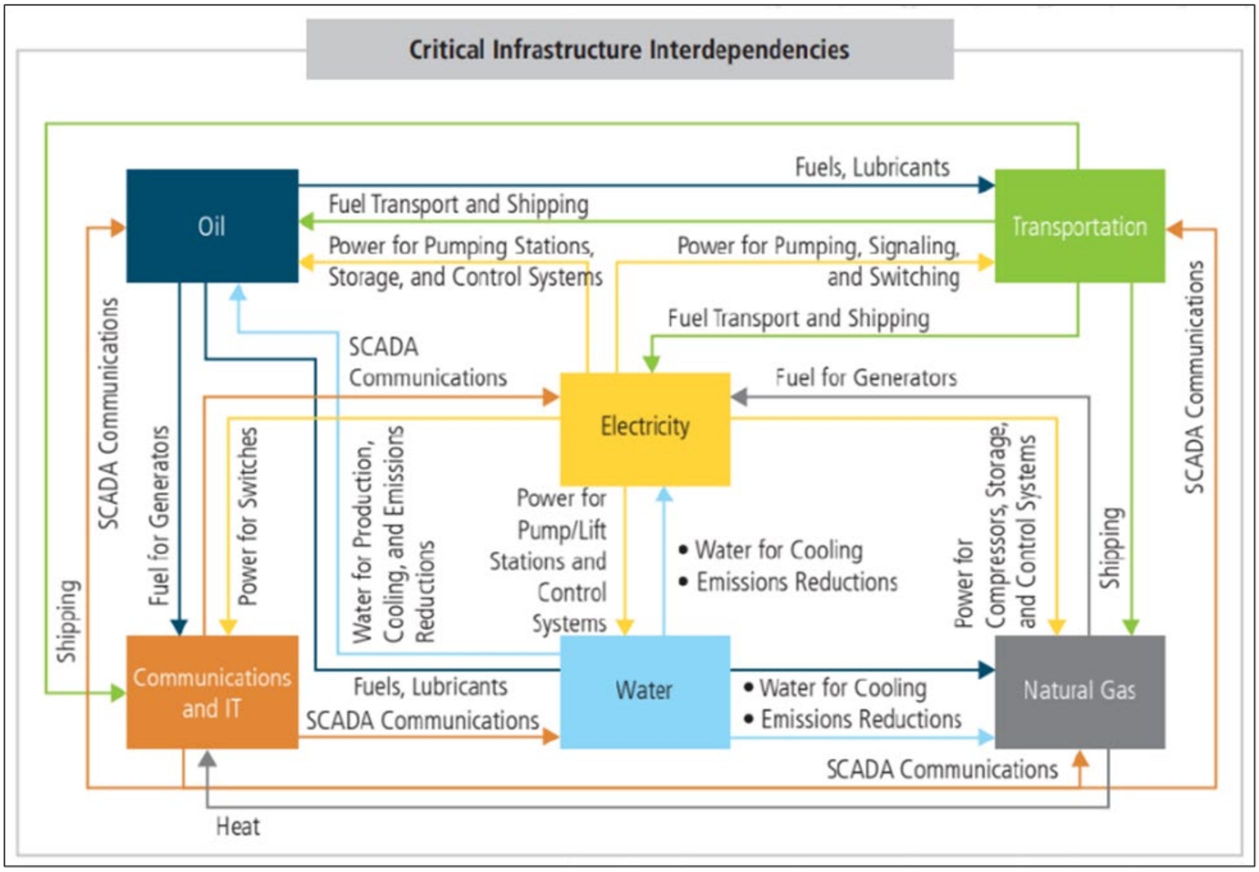

Figure 2: Critical Infrastructure Interdependencies in Electricity, Oil, Transportation, Natural Gas, Water, and Communications and IT

With the right design, construction, maintenance, investment, and planning, a reliable grid allows customers to confidently anticipate that generation, transmission, and distribution facilities will be adequate to meet anticipated energy needs.

Grid reliability is measured in minutes of outages that customers are likely to experience and the frequency at which these outages are likely to occur. Grid reliability varies regionally and, in fact, even in pockets within a certain provider's system. Where the grid is least reliable, all uses that depend on grid energy become less attractive. For example, car owners who experience several outages per year may not feel comfortable entrusting their transportation needs to an EV that cannot be reliably charged, given an outage. Likewise, homeowners in cold climates may hesitate to move from gas or propane heat to an electric heat pump.

Reliability is the most developed measure of grid performance. Achieving reliability performance depends on significant ongoing capital investment and maintenance activities and, in turn, on the workforce that plans, designs, installs, and maintains grid facilities. Across the past decade, the communication and visibility of the power grid has advanced, deploying new technologies such as advanced metering infrastructure on the last mile of the grid so that utilities and system operators know more than ever before about when and how customers are using electricity and how the grid is performing for these customers. Understanding the characteristics of customers' power use will allow providers to optimize delivering electricity that accounts for and balances peak demand periods with peak generation, with respect to intermittent renewables.

One of the chief concerns for electrification is whether customers will encounter new reliability and power quality issues as the generation and use of electricity changes. While this report focuses on the impact of electrification as new uses are added to the grid, many factors affect grid reliability, including changing sources of generation, extreme weather events, new communications and control technologies, and technology obsolescence, and these risks must be managed in concert. Grid performance cannot be allowed to dwindle given the increasing value of reliability to end users who are turning to electrification. Future-state reliable grids must be tailored to customers' demand characteristics to take advantage of the generation, storage, and distribution technologies with the most reliable, efficient, affordable, and clean generation available.

The grid has already undergone a significant transition as legacy coal generation has been retired and as natural gas-based generation has taken its place. Between 2008 and 2014, there was a 20% reduction in mortality damages attributable to fine particulate (PM2.5) pollution as "recent closures of coal plants and fuel-switching to natural gas have drastically reduced environmental damages from [the power] sector".[12] The pace and direction of these changes boosts confidence that the grid can adapt to changing needs and adjust to a changing generation resource mix over time, provided that adequate grid resources are commissioned in advance of the demand that they serve.

Planning a reliable and resilient grid depends on utilities having foresight into future grid conditions. In this regard, planning is complicated when there are properties with installed solar generation and batteries that, at times, draw from the grid and, at other times, power it, thereby masking the true electricity demand profile of the location. Further, devices like high-power home EV chargers complicate grid planning if market and regulatory incentives are not established to incentivize off-peak charging and disclosing customer electrification behavior. Finally, climate change is causing increasingly volatile weather patterns, including periods of both severe heat and extreme cold. Utility assets can routinely have life spans of three decades or longer. Grid owners, operators, and participants must have the computational tools and market structures to facilitate appropriate, targeted investments to ensure the grid-based resources and resources that are behind-the-meter can be relied upon to maintain reliable and secure electric service.

Reliable grids under high electrification scenarios will require a costly increase in the margin reserved for contingency scenarios and/or advanced analytical and computational capabilities with additional sensors and control systems to coordinate a diverse, distributed, and automated grid.

A final grid consideration relates to outage scenarios for winter-peaking system components where customers are reliant on the grid for electrical heat. According to PJM Interconnection, under many electrification scenarios, grid peaks will shift from summer to winter and the electrical grid will need to adapt to provide reliability for those peaks.[13] These concerns have been central to the public awareness of grid reliability, particularly within the Electric Reliability Council of Texas (ERCOT). In the 2021 Texas power crisis, there were 246 confirmed winter-storm related deaths, 161 of which were due to cold-exposure

[12] Peter Tschofen, Inês L. Azevedo, and Nicholas Z. Muller, "Fine Particulate Matter Damages and Value Added in the US Economy," *Proceedings of the National Academy of Sciences* 116, no. 40 (September 9, 2019): 19857–62, https://doi.org/10.1073/pnas.1905030116.

[13] Economic factors still dominate near-term load growth drivers, but electrification is anticipated to become the leading indicator. The California Public Utility Commission electrification study anticipates a 56% growth in system peak between 2025 and 2035. ISO New England estimates that a ten-year peak in cold weather ("90/10") would produce a system peak that is 34% higher in 2033 than 2024 due to transit and heat electrification, approaching the region's summer peak.

related injuries.[14] Given the gravity of these risks, the shift to a winter-peaking electrical system may require additional levels of critical redundancy and careful reliability planning.

4.1.2. Grid Resilience

Utilities differentiate between reliability and resilience to capture the specific operational capabilities and performance outcomes in recovering from adverse events. While there are measures of system resiliency, resiliency planning often needs to encompass specific hazards. Actions taken to plan for recovery from cybersecurity, wildfire, physical intrusion, and geomagnetic disturbances require different initiatives that address the appropriate issues at the appropriate scale.

Climate risk has moved from a decades-forward point for awareness to a near-term consideration in many companies' risk management procedures. Many communities are already updating engineering procedures to account for changing temperatures, wildfire risk exposure, and increased hurricane risk. To be resilient to climate risk, utilities must identify asset vulnerabilities and manage them by implementing climate adaptation plans. In the context of electrification, climate change is a source of uncertainty that makes the task of establishing a reliable and resilient grid that much more difficult, thereby reducing the predictability of system planning and operation. Fortunately, with increasingly sophisticated and downscaled (more granular and localized) climate models, decision makers have access to more information on climate risk than ever before and more opportunities to develop effective and targeted climate strategies.[15]

Wildfire risk management is one example of a targeted climate resilience strategy. Utility companies have a unique and important role in managing fire risk associated with power infrastructure under atmospheric stress conditions, such as drought, high winds, and storms. With greater frequency and intensity of storms and droughts, electric utilities find themselves with a Hobson's choice: de-energizing significant parts of the grid or risk sparking wildfires that pose an extraordinary risk to life and property. Policies such as the California Public Utility Commission's Public Safety Power Shutoff (PSPS) initiative may need to be widely adopted to control risks. With sufficient planning, utilities and their communities can mitigate the secondary impact of PSPS events. For example, a duty of care is owed to individuals with disabilities and households that need electricity to power medical devices. These households require special consideration and accommodation in the management of shutoff impact.

Cybersecurity risk is inevitable when using advanced information systems that have been relied upon for many aspects of customers' and utilities' energy operations. In the context of electrification, the opportunity to shift the timing of loads to align demand with available renewable supply depends on a set of communication and control technologies that inherently increase grid risk by adding more internet-connected devices to the grid. For instance, attacks could disable devices that are necessary to perform critical functions, like strategically located EV chargers, or could overburden grid assets by aggregating devices to increase loads and decrease distributed energy resource (DER) output during system peaks. Even as utilities continue to invest in their own cyber-risk management strategies, Edison Electric Institute identified a need for a more holistic approach to cybersecurity risk management. One specific example of

[14] John Hellerstedt M.D., "February 2021 Winter Storm-Related Deaths - Texas," December 31, 2021, https://www.dshs.texas.gov/sites/default/files/news/updates/SMOC_FebWinterStorm_MortalitySurvReport_12-30-21.pdf.
[15] See, for instance, ComEd's 2022 study with the Argonne National Laboratory on Climate Risk and Adaptation, https://publications.anl.gov/anlpubs/2022/12/180058.pdf

this was proposed in a briefing by ChargePoint, where utility-grade sensors were suggested as a check on behavior that is behind-the-meter behavior.

Where threats are identified, additional connectivity and dynamic systems will be the key technologies that allow grid operators to rapidly respond. Such a scheme is consistent with a "zero-trust DER" approach that allows for DER-operational behavior without designing the grid with the assumption that the operational behavior will always be compliant. Establishing the capabilities and market mechanisms necessary to use energy efficiently while also maintaining the fundamental resilience of the grid to cybersecurity threats is essential. Electrification, and particularly vehicle electrification, brings extraordinarily flexible loads onto the grid. Most EVs provide a week or more of range given an average daily drive of 30 miles, opening the possibility of voluntary multi-day shifting of EV loads to manage grid capacity considerations. This capability would have significant value in reducing the cost of grid capacity (i.e., generation, transmission, and distribution) buildouts that will support electrification, provided that the cybersecurity risks can be managed to rely heavily on charging management.

Recent incidents involving attacks on electrical substations have also highlighted the importance of physical security. Because a significant portion of grid infrastructure is located outdoors and because energized equipment is potentially vulnerable to threat actors, security strategies continue to be a salient consideration in the design, construction, and optimal operation of the electrical grid. Electrification does increase the number of energy end uses that are vulnerable to a physical attack on the grid, but this exposure is spread over additional assets as well. One area where novel risks are emerging is in cyber-physical security, where protection from physical intrusion is the first layer of defense for critical information technology assets. These risks apply to the equipment and real-time control systems that operate the grid, the proliferating array of internet-connected loads and generators, and the centralized data infrastructure that supports aggregating grid-edge technologies.

While threat actors are key considerations in grid security and electrification risk, natural disasters also warrant careful consideration. Climate change risk is already driving a new wave of grid adaptation analyses as utilities seek to ensure that grid assets can handle the heat, ice, hurricane, flooding, wind, and fire risks that now characterize the operational environment for many utilities. During a briefing to the NIAC, the DOE referred to a joint initiative with the Electrical Power Research Institute (EPRI) to investigate coronal mass ejections (CME) and electromagnetic pulse (EMP) attack threats. Depending on geological conditions and the rotation of the earth at the time of a solar flare, a resultant CME has the potential to substantially impair a significant component of the U.S. power system, causing outages that could last weeks or months and destroying transformers that are currently backordered for years.

The Congressional Budget Office (CBO) investigated a policy proposal to create a strategic transformer reserve,[16] and it identified various incentives that may be established for either a public or private reserve stock of power transformers. The CBO noted the following in its investigation:

> "Private-sector electricity suppliers have a greater incentive to pursue some of the benefits associated with investing in reserve transformers. As a result, suppliers hold their own reserves, both individually as part of their business planning and collectively in reserve-sharing arrangements."

[16] U.S. Congressional Budget Office, "Enhancing the Security of the North American Electrical Grid," March 2020, https://www.cbo.gov/system/files/2020-03/56083-CBO-electric-grid.pdf.

Much has changed since 2020, including an increase in supply chain disruptions that have drawn down available transformer reserves. It is a matter of national security that these reserves be supported to ensure that equipment may recover from a catastrophic grid event. Reserves could also be drawn upon in other unprecedented circumstances that impact other sectors. Given the wide exposure of the electrical grid to both threat actors and natural disasters, the ability to quickly reconstitute systems with temporary and then permanent restoration measures is a critical capability in managing catastrophic risk to the electrical system.

4.2. Transportation Sector

Transportation is one of the most actively electrifying sectors. Efficiency gains, long-term price stability in electricity, and reduced maintenance costs are driving many fleets to consider EVs as a promising alternative to legacy vehicles. While some vehicles have daily non-critical routes that can be adjusted or avoided in the case of short- or long-duration outages, disruption to long-haul and critical transportation infrastructure may have cascading impacts to security and community needs. Transit is itself critical infrastructure that can be locally disrupted. An electrified transit system has the potential to be interrupted regionally in the case of a significant grid disruption, stranding residents and essential workers in the process. While the risks of these disruptions can be mitigated with on-site generation or redundant energy supply, it is likely that most charging stations will be configured without these costly design additions, leaving distribution utilities with increasing responsibility for transit continuity and further underscoring the need for active planning of reliability and resilience. In some cases, infrastructure may need to be installed with microgrid or backup capabilities that can secure energy supply to the most critical transportation functions during several different contingency scenarios.

Fleet electrification ranks among the most active processes of mass electrification, bringing dense loads to businesses that were previously light users of electrical infrastructure and reducing tailpipe emissions in the process. As fleets electrify, appropriate levels of reliability and resiliency must be developed to serve the downstream needs of fleet operators' customers. To achieve this result, effective communication is essential between utilities and electrification customers who must, together, actively prepare for specific contingencies far before the events that require them. In some cases, low-carbon-fuels may be preferable to EVs because these fuels can be more easily secured as a resource stock during outages. However, a long-duration outage that interrupts fuel generation or delivery could also have repercussions for fuel stocks that must be considered in resiliency planning.

The NIAC received a briefing that discussed concerns with emergency transportation needs once EVs become a significant mode of transit. Emergency evacuation (e.g., hurricane evacuation) is an example where it may be necessary to charge an unprecedented number of vehicles in a constrained time period to avoid causing traffic backups that delay all vehicles as a consequence. These considerations can be managed with sufficient planning, but careful planning and coordination is required to do so. Likewise, in the recovery phase of extreme events, grid resilience becomes a critical antecedent to reestablishing transit service from an electrified fleet. In each of these cases, the critical concern is grid capacity and sufficient charging infrastructure at location. The recent developments in charging infrastructure through Federal funding have been significant, and yet the NIAC notes that Federal rest area infrastructure has yet to be revitalized with charging infrastructure and that other least-cost charging locations must be utilized to ensure timely and affordable access.

Another risk in the transportation sector arises within the network of EV supply equipment. To connect this equipment for remote updates and payment processing, nearly all the public chargers and many household chargers must be connected to the internet. These connections are the principal pathway by which utilities send smart charge management signals to govern charging behavior during peak events. However, there is a risk that a cyber threat could render the equipment non-functional to disrupt transportation or successfully attack the grid by coordinating charge and discharge cycles to increase coincident demand during system peaks.

4.3. Communications Sector

Communications systems provide essential services that allow for the coordination of emergency response, day-to-day business continuity, and the practical connectivity that is fundamental to the way that we solve everyday problems. The NIAC identified two key issues related to communications and electrification:

- the need for redundant communications capabilities in the energy sector, particularly with respect to black start[17] vulnerabilities, and
- the increasing scope of complex communications disruption risk, particularly as a byproduct of potential cyberattacks.

Because many generators have long startup procedures and slow ramp rates, restarting the grid requires significant coordination that tends to presume the availability of adequate communications between generation, transmission, and distribution system operators. When FERC briefed the NIAC, the briefers emphasized that infrastructure owners must be prepared for communications disruptions during significant events and for communications as a potential source of the disruption. These risks are not unique to scenarios with widespread electrification, but they can disrupt electrified energy uses if the energy system relies upon real time communications networks or has not been designed for adequate communications resilience.

A second concern is that the communications system itself is a source of vulnerability. Disrupted or hijacked communications systems have the potential to signal grid configurations that could cause damage to equipment and disrupt the grid's ability to operate. Unintended access to grid configuration data could allow a threat actor to engineer the location and timing of a damaging attack. Performance-based regulation can be used to encourage appropriate advanced planning and operational security to mitigate the worst of these threats; advanced planning and operational security are strategies that are essential for resilient grid operations given intended harm by both state and non-state actors.

4.4. Financial Services Sector

While prolonged and sweeping outages that encompass both electrical and communications infrastructure would also directly impact this sector, many of the risks in financial operations can be mitigated by resilient and redundant energy sources to ensure that critical data is maintained and available under any condition. While electrification does increase some public risks of electrical outages, these risks are already known to financial services operators. The NIAC has not identified any new risks in the sector during its research for this report.

[17] "Black start" refers to the process by which the grid would gradually add generation and load in the case of a major regional outages.

4.5. Critical Manufacturing Sector

Many industrial manufacturing processes are both energy and capital intensive, which means that grid disruptions come at a high cost, and adequate backup facilities are not always cost-effective to install. For less energy-intensive manufacturing processes, it is more common to find facilities with their own energy resilience capabilities installed onsite. Another special consideration for outage impact relates to continuous production processes that experience significant material losses and long restart times whenever power is disrupted. Special planning is necessary across these cases to ensure that manufacturing processes have adequate resilience to avoid financial and operational damages.

A second and distinct consideration is the impact that some industrial electrification can have on grid operations. For example, electric arc furnaces (EAF) can impact power quality, which, in turn, can damage grid equipment or disrupt other entities' operations.[18] These narrow operational considerations can be mitigated by design choices in the technology, provided that new technologies are carefully studied in both their design and in the interaction between that design and the grid's other uses.

A final concern in critical manufacturing relates to the downstream price impacts of new technologies and material availability amidst mass electrification. In general, there are very significant changes in material supply chains and average annual demand for key inputs like copper, and the rapid increase in demand for these materials can impact other critical sectors that use significant amounts of these resources. Furthermore, electrifying extraction and refining processes may provide some efficiencies, but significant sector-specific cost increases for material input are also anticipated, particularly in materials like concrete, carbon fiber, and ceramics, which have significant thermal inputs that are difficult to electrify. To the extent that electrification processes add costs into these materials, cost increases will cascade in ways that can be difficult to predict and manage. Where critical businesses participate in price sensitive markets, operational challenges can be anticipated.

4.6. Community Risk Factors

In addition to the sector risks outlined above, adopting new technologies within existing social, political, and economic processes will also shape the community impact of electrification and introduce community risks. The NIAC identified several key socio-technical risks for an electrified future:

Energy Poverty

Energy poverty occurs when households are unable to afford the energy resources that they need to live safe, productive lives. Unfortunately, with rising home prices, low rates of owner-occupied housing, aging housing stock, and suburban poverty, some prudential efficiency investments that can mitigate the consequences of energy poverty by making energy bills more affordable may not be accessible to many customers. In a briefing to the NIAC, the National Renewable Energy Laboratory (NREL) discussed one socio-technical challenge with equitable electrification in housing: it has proven complicated to incentivize building owners to upgrade building efficiency without also raising the price for renters. Utilities, green innovators, and Federal programs must work together to ensure that the benefits of electrification reach

[18] Horia Andrei, Costin Cepisca, and Sorin Grigorescu, "Power Quality and Electrical Arc Furnaces," in *Power Quality*, 2011, 77–100, https://www.researchgate.net/publication/221911830_Power_Quality_and_Electrical_Arc_Furnaces.

the individuals and households for whom they were intended to serve, a task that is significantly complicated by building ownership incentives that favor market appreciation over customer appreciation.

Pace of Innovation

Technologies for EVs and heat pumps have been field demonstrated within commercially available products, indicating a high level of technical readiness. Yet, the public knowledge of these products and the needs of the workforce may prolong adoption for decades. To foster a positive public experience with innovative product adoption and to answer the many questions raised by new technologies, adequate training must be available to the relevant workforce, new processes must be established and managed, and new supply chains developed. While the pace of innovation is one of the bright hopes in electrification, early adopters, national laboratories, and universities can play an important role in helping to speed the diffusion of efficient and productive new ideas.

Supply Chain Risk

Even if the pace of innovation can be managed from an adoption perspective, there may be insufficient supply chain development to support electrification growth. The challenges in electrification supply chains are deep and wide. Materials for batteries are sought in unprecedented quantities, demanding rapid development of both extraction and manufacturing capacity. As mentioned above, transformers are another critical technology that will need to be ramped up to ensure that distribution capacity is available when it is needed. It is also worth noting that supply chain capacity is not only measured in output, but also in the supply chain's ability to efficiently make use of materials. Given the significant human rights and environmental impacts associated with battery materials extraction and battery production, action is warranted to ensure that battery energy storage systems are manufactured for recyclability and that resources are set aside to recycle them to recover critical supply input and reduce harmful environmental consequences from the battery waste stream.

Product Quality and Consumer Confidence

Both new market entrants and incumbents are experiencing costly recalls and manufacturing challenges as they work to integrate design and production techniques. For instance, the Southeastern Pennsylvania Transportation Authority (SEPTA) (the regional transit agency in and around Philadelphia) was an early adopter of electric buses and has faced multiple reliability issues with the initial purchase. One bus was incinerated in a fire apparently caused by a battery failure while the bus sat in a storage yard because of a cracked chassis.[19] SEPTA recently announced an order of ten hydrogen fuel cells vehicles, a strategy that was almost certainly selected in lieu of battery electric alternatives as a consequence of the first mover disadvantage that stems from unreliable technology. Federal programs can play a key role in de-risking early phase demonstrations to minimize the impact of supplier mistakes, but small-scale demonstrations over some period of time are essential to ensure that investments produce anticipated results.

Grid-Edge Control Systems

These control systems present a risk to the grid in terms of cybersecurity, but they provide an opportunity for customers to better manage their energy use to limit infrastructure costs and energy consumption and to enable diverse energy choices presented by customer installations of solar panels, batteries, and other

[19] Ryan Briggs and Thomas Fitzgerald, "A Proterra Electric Bus Battery Caught Fire in a South Philly SEPTA Depot," https://www.inquirer.com, November 11, 2022, https://www.inquirer.com/transportation/septa-proterra-electric-bus-battery-fire-philadelphia-20221111.html.

technologies. DER can provide significant global and locational value to the grid, but basic barriers to broadband access within communities may hinder residential access to these technologies. The efficient deployment and control of DER can alleviate these same electrification constraints, reducing overall grid costs and increasing grid flexibility. Mismanagement of DER adds additional uncertainty to the stack of resources and controls that govern electrification outcomes, compounding the risk of unanticipated grid conditions that can cause issues in reliability and safety.

5. Recommendations

Given the range of electrification challenges to the grid, communities, and critical sectors, concerted effort is warranted to effectively plan for and mitigate risks. Risk management depends upon four central strategies:

- adequacy, tailoring grid infrastructure to the unique demands of its customer base;
- efficiency, reducing the impact of electrification;
- security, anticipating and mitigating threats; and
- unity, coordinating standards-based strategies to manage electrification risk.

These strategies and specific recommendations from NIAC are outlined in the following sections.

5.1. Adequacy: Preparing for Impact

5.1.1. Reliability Forward

Energy is a critical input for time-sensitive processes that meet public needs. An adequate grid is a combination of generation, transmission, and distribution resources that can generate and deliver power safely, reliably, and resiliently. One goal is for this grid to be as clean as possible as quickly as possible, but this goal must align with reliability mandates.

The NIAC endorses a reliability-forward electrification strategy and emphasizes that electrification goals should not be met at the expense of a reliable grid. To avoid faltering in reliability planning and performance, dispatchable generation (generally fossil-powered and fueled by natural gas) must be available during system peaks until alternative technologies and market mechanisms can be established to provide grid reliability. There are public safety concerns when dispatchable resources to meet system peak for critical household and building loads are unavailable during the hottest and coldest days of the year. Moreover, given climate change impacts, including polar vortex instability and record-breaking heat, it is more difficult than ever to anticipate extremes and ensure new facilities are adequate to meet them. Additional focus on advancing technologies that will minimize the grid impact of electrification while establishing additional resiliency capabilities is implicit to strategically improving reliability performance during mass electrification.

In the context of electrification, adequate grid buildout must include sufficient resources to maintain operational flexibility for contingency. Electrification is already having an impact on the grid, and the impact is complex across a “system of systems.” Adequate contingency resources can mitigate the cascading impacts that are most difficult to anticipate amidst this complexity. Furthermore, as grid uses change and climate risk exposure increases, the grid may also need to change to maintain or improve reliable performance. These operational needs are supported by more robust interconnections between independent system operators (ISO) and improved transmission resources across the seam between the Western and Eastern interconnection.[20] In light of these needs, the NIAC suggests an initiative that would:

> **Endorse a state and Federal, equity-centered, reliability-forward electrification strategy,** establishing that policies and regulations on electrification must be paired with adequate planning and investment in the relief supply, delivery, and storage of power to ensure that grid capacity

[20] NREL, “Interconnections Seam Study” https://www.nrel.gov/analysis/seams.html.

development in generation, transmission, and distribution stays ahead of electrification demand for all communities.

Many electrical grid customers throughout the world experience uncertainty in their grid services with frequent outages, blackouts, and brownouts. A reliability-forward electrification strategy requires that grid performance issues be addressed alongside or in advance of growing electrical demand and that these improvements be distributed equitably and nationally. The process of residential, commercial, and industrial electrification will require significant investments to achieve efficient and consistent performance with electric alternatives to traditional fossil fuel energy uses. Grid reliability is an essential assumption upon which justifications for these investments must be based. Accordingly, NIAC strongly endorses the principle that reliability and resilience are a paramount consideration to support customer needs in a more heavily electrified society. By ensuring that new investments are cost-effective, flexible, clean, and resilient, overall grid reliability advance while maintaining other key performance criteria that are drivers of electrification's net benefits. To ensure full participation in electrification benefits, infrastructure must be installed and maintained equitably. The NIAC emphasizes the importance of electrification equity, as embodied in the Justice40 Initiatives,[21] and suggests that equitable access is maintained as a key benchmark in advancing reliability.

5.1.2. Advanced Planning Tools

Grid operators cannot achieve grid adequacy without sufficient planning and planning tools. They need to know how much new load is coming and where it is coming from, and they need to stay ahead of the grid impacts of DER, which can mask the changes in the load on different feeders. Grid operators must also account for changes in the climate, which may reduce the grid's capacity to serve customers on the hottest days of the year. Planning is needed nationally, regionally, and locally to ensure that cost-effective resources are available when and where they are needed. Advanced planning tools must be further supported by publicly accessible and widely supported forecasting tools that can guide the capital allocation planning and regulatory authorization processes that major grid investments will require. Improved data quality is a critical input to planning and forecasting tools, without which, these capabilities cannot advance. This includes reanalysis of weather data for renewables, load forecasts for new building profiles, and combined electric and gas demand data, all of which would provide significant benefits to aid in planning and forecasting. The results of advanced analytics and planning tools, once fully developed, will have additional value at the grid edge to establish new market mechanisms that identify least-cost solutions for a dynamic, affordable, resilient, and clean future grid. The NIAC recommends the following action:

> **Establish a Federal resilience framework with state regulatory participation and regional transmission organization (RTO) input** to guide the deployment of advanced planning and modeling tools that provide consistent and objective input on capacity planning, project prioritization, location-specific resilience to climate emergencies, and targeted resilience strategies to address community and business needs.

While planning tools should be designed for plausible, near-term scenarios, they may also provide the ability to model 100% decarbonization and near 100% electrification given the complexities of grid configurations, regional access to renewable resources, and other local conditions. It is likely that the grid will continue to rely upon fossil fuel generation for several decades, particularly during demand peaks. At the same time, it

[21] White House, "Justice40 Initiative," https://www.whitehouse.gov/environmentaljustice/justice40/

is also clear that, without significant advancement in planning tools, it will not be possible to optimize the decarbonization strategies that can promote an adequate, safe, reliable, and affordable grid. The NIAC was briefed on the importance of forecasting for changing energy in multiple briefings including comments by Edison Electric Institute, EPRI, PJM, NREL, Office of Science and Technology Policy (OSTP), and others. The NIAC also discussed the need to quantify the uncertainty within scenarios and to rely upon ensemble models to do so. For instance, McKinsey described the uncertainty in regulatory mandates and the availability of vehicle supply and charging infrastructure as key drivers of model uncertainty in rates of electrification.

The utility industry could better serve the public with the help of long-term planning for scenarios of higher electrification and changing climate. EPRI emphasized the need to update planning insights to new scenarios, such as grid readiness for cold weather extremes with high utilization of electric heat. The North American Electric Reliability Corporation also emphasized a similar point, highlighting the challenges of rising electrification amidst retiring fossil fuel generation. Predicting the impacts on increasingly local levels can help to inform resilience investments. While some of those investments will support regional and even national recovery efforts from extreme events, some of the most cost-effective approaches to resilience are targeted, placing additional grid resilience capabilities in the buildings, blocks, or neighborhoods where they matter the most, including historically disadvantaged communities. A Federal framework to advance grid resilience – as well as an effort to connect utilities, state energy officials represented by the National Association of State Energy Officials (NASEO), and regulators represented by NARUC to entities such as national laboratories that possess sophisticated tools based on a common framework – could help to establish locational needs while also informing key decision-making inputs to ensure wider preparedness across the sector. The NIAC received information on equity and environmental justice from discussions with OSTP and in NREL briefing materials.

5.1.3. Supply Chain Adequacy

The buildout of the grid is likely to be an unprecedented effort in the decades to come, and it cannot be achieved without an adequate supply chain. Critical equipment serving generation, transmission, and distribution investments to build new facilities and upgrade existing ones will exceed the existing production capabilities of electrical equipment manufacturers. These manufacturers are already behind, and active industrial policy has a role to ensure these critical security resources are available for grid deployment that stays far ahead of grid needs. As production ramps up, there is also a need to ensure new systems are capable of state-of-the-art interoperability in communications and controls. An open, standards-based configuration ensures that new equipment can be rapidly deployed and maintained for decades of field operation. These initiatives must be undertaken with a spirit of minimalism that seeks to cost-effectively deploy control systems, DER, grid-edge devices, and energy efficiency investments that can alleviate the strain on both the grid and the critical supply chains that support its growth. It is in the context of an advanced, dynamic grid that uses grid resources as efficiently as possible that additional reserves in critical assets will have the greatest value.

Insufficient production capacity for key electrical system equipment is already lengthening timelines for important grid capacity projects. Supply chain issues in electrical equipment must be addressed to get ahead of electrification and to restore inventory levels that are themselves a resilience resource. Accordingly, the NIAC suggests an initiative to:

> **Actively address supply chain issues through policy in the electrical equipment sector and plan to establish a strategic reserve of key electrical equipment.**

The NIAC discussed supply chain disruption in the electric sector in multiple briefings, with specific reference by Edison Electric Institute and the DOE's Office of Cybersecurity, Energy Security, and Emergency Response. To be sure, the supply chain for components such as transformers, batteries, and motors is already strained, and it will become more strained due to growth. However, the potential unavailability of electrical equipment such as power transformers can dangerously delay recovery in the event of natural or deliberate attacks on the system. Policies to secure adequate supplies of these items must be in place to achieve grid buildout objectives and to ensure resilience against damaging events. As highlighted in the investigation on the subject by the Congressional Budget Office, there are many entities within the supply chain that may have an opportunity and motivation to maintain an inventory of transformers. The NIAC recommends working with relevant agencies and industry groups to explore ways that increase manufacturing output to meet demands for expansion of the electrical system and to establish and maintain strategic inventories. This will allow grid operators to better manage grid development timelines, limit the likelihood that grid developments could hinder the adoption of electrification options by customers in the future, and allow for faster recovery in the event of widespread outages.

5.2. Efficiency: Reducing Impact

Many forms of efficiency have the potential to reduce the grid impact of electrification, and an important subset of these efficiency strategies provide cost-effective alternatives to grid capacity expansion. More work is needed to ensure that a range of automotive design standards, building codes, and professional practices are using the best tools available to ensure that major investments are designed appropriately for a future energy system. To this end, active public and private sector R&D programs must continue to foster innovation in cold climate heat pumps, electric motors, batteries, induction cooking, energy recovery ventilation, and high efficiency buildings to reduce the cost and grid burden of electrical alternatives. In general, the operational playbook currently relied upon by buildings with hybrid natural gas and electric operations to decide how to shift or shave peak demand will need to be revised and reconsidered as electric alternatives are deployed.

Additionally, special care must be taken to ensure markets leverage the benefits of efficiency. EV efficiency improvements are a key market consideration that customers value through their focus on vehicle range. The [EPA's National Vehicle and Fuel Emissions Laboratory] helps to validate marketing claims. However, while miles-per-gallon is a widely understood measure of vehicle efficiency that has been adapted to miles per gallon of gasoline-equivalent (MPGe), the equivalent measure of efficiency for buildings, Energy Use Intensity (EUI), has almost no public recognition or understanding. Moreover, existing real estate processes may not be sufficient to properly value the reduced energy intensity and resilience of an efficient building. It is worth noting that many of the deaths that occurred in the 2021 Texas power crisis could have been avoided if the building codes provided a higher standard of energy efficiency.[22] More work must be done to advance energy efficiency technologies and to ensure that the value of these technologies is fully realized in the marketplace so that an optimal level of investment in efficiency is available to mitigate the impact of electrification.

While this section focuses on energy efficiency, economic efficiency and cost-effectiveness are also critical aspects of electrification. More than one briefing noted the importance of permitting reform in advancing capacity expansion projects that have languished under the current standards and processes. Likewise, the

[22] Sneha Ayyagari, Michael Gartman, and Jacob Corvidae, "Hours of Safety in Cold Weather: A Framework for Considering Resilience in Building Envelope Design and Construction," *RMI.org*, 2020, https://rmi.org/insight/hours-of-safety-in-cold-weather/.

NIAC reached a consensus that grid buildout should be mitigated by cost-effective technologies that can reduce system peak and customer needs. In the case of permitting reform, developing efficient market mechanisms that provide incentives to customers is one of several strategies regulators and grid operators can deploy to make the grid more affordable and adaptive to extreme conditions. Efficient build perspective should account for the changing demand that is anticipated in the next decade. By advancing grid capabilities ahead of renewable interconnection queues and electrification loads, grid operators may be able to manage costs in ways that directly benefit customers. One of the key findings from the California Public Utilities Commission's Electrification Impacts Study is that integrated distribution, transmission, and generation planning must be undertaken on a longer time horizon. This enables planning for capacity constraints fifteen years in advance rather than the current distribution planning horizon for utilities, which is generally five years in advance.[23] Other market mechanisms on the customer side are also worth considering. For example, there is a general lack of transparency in the supply chain of heat pumps. Consequently, potential heat pump adopters may receive wildly disparate bids for the same equipment, which undermines customer confidence in the maturity of these markets. In other cases, where markets are more mature, legacy policies are hindering the efficient use of available resources. For instance, policies precluding development of charging infrastructures at interstate rest stops hinder least-cost deployment options that would support vehicle charging.

Efficient energy use encompasses not only total energy usage but also the efficiency of grid assets that are used to serve these needs. Load management technologies, such as Grid-interactive Efficient Buildings and EV smart-charging management, can adjust grid-edge device behavior to reduce system impact. Here, too, there is work to be done to extend the technical capabilities and intelligence of devices and systems.

5.2.1. Joint Intermodal Transportation and Electrification Planning

Energy efficiency initiatives tend to focus on devices. However, electrification impact is shaped more broadly by the energy intensity of human behavior. For instance, when businesses host virtual meetings in lieu of on-site engagements, the energy impact of the interactions is reduced by orders of magnitude, whereas device-level efficiency improvements may only account for a few percentage points of change. Likewise, where mode switching and transportation-oriented city planning can eliminate car trips, the results have the potential to alleviate both grid and road congestion. A similar principle may be applied to an advanced planning tool that evaluates diverse transportation modes. In this regard, NIAC proposes that:

> **The Department of Transportation develop, in collaboration with the DOE, a roadmap for efficient electrical transportation** to help infrastructure planners to know how and where different modes and fuels should be used.

The NIAC received a briefing on transportation electrification planning initiatives at both the Los Angeles Metropolitan Transportation Authority and the Denver International Airport, but the NIAC was unable to identify a broad national attempt to plan for efficient transportation mode selection in electrification. A roadmap for the energy systems needed and optimal transit mode choice could help policymakers evaluate where hydrogen-fuel cell vehicles may be preferable to battery-electric alternatives on long routes and where electrification may better serve transportation needs. After the briefing from the American Association of Port Authorities, the NIAC discussed maritime transportation as a mode that can sometimes

[23] See page 120 in California Public Utilities Commission, "Electrification Impacts Study Part 1: Bottom-up Load Forecasting and System-Level Impacts Cost Estimates," May 9, 2023.

provide an efficient alternative to long-haul trucking. Utilizing maritime options, where appropriate, can remove considerable volumes of cargo off the road and help shift focus toward trucking resources on regional routes that are more easily electrified. Rail transportation is another example of a mode that provides efficiencies relative to road transportation. The DOE ARPA-E Intermodal project awards encourage promising results to optimize cargo flows by minimizing costs, energy inputs, and emissions outputs. More work in this area is needed at the nexus of grid and transportation planning. The NIAC believes that these initiatives would benefit from careful study and Federal guidance and that, in turn, these initiatives can be drawn upon to inform future electrification policy.

5.2.2. Industrial Electrification Cohort Support

Where transportation and building electrification require general, economy-wide initiatives with targeting to fill in the gaps, industrial electrification involves a great deal of specialization in how electrification technologies can be designed and deployed. Accordingly, the NIAC suggests an initiative to:

> **Build advanced R&D support for industrial electrification by establishing technology demonstration partnerships between the DOE, national laboratories, industry organizations representing candidates for industrial electrification, and local distribution utilities.** As a result, these planning initiatives and collaborations with utilities can ensure that significant new loads are adequately accounted for in system planning and grid impact studies.

Industrial processes are naturally proprietary. Today's DOE proposals tend to look for businesses to seek funding and look to proposers to disseminate results. However, there is room for additional outreach, particularly where clusters of businesses that have similar energy needs can learn together in regional cohorts. Utilities can organize these cohorts and help participants understand the specific benefits that come from long-term planning that includes industrial customers' business plans and grid planning processes. One of McKinsey's reports reviewed by the NIAC proposes that governments can "develop roadmaps for industrial decarbonization" and that "governments, industrial companies, and research institutions can support innovation and the scale up of promising decarbonization technologies."[24] Collaborative efforts related to EV deployment have helped significantly advance transportation electrification. The DOE should consider convening representatives of industrial customers, utilities through the Edison Electric Institute, and EPRI to explore advanced opportunities to address hard-to-electrify sectors. Furthermore, a network of electrification extension offices that mirror the Department of Agriculture's Co-op Research and Extension Services may warrant consideration.

In addition to the direct consumption of electricity by industry, many industrial customers are anticipated to consume increasing quantities of hydrogen and hydrogen-derived fuels. As the next generation of electrolyzers is connected to the grid to produce hydrogen for direction consumption and as a feedstock, these installations promise to have a grid impact of their own. Given the inefficiencies in conversion, storage, and use, a fuel-based approach will have an even greater grid impact than an industrial process that can make direct use of electricity. As such, the planning insights that derive from industrial electrification must be maintained and fed directly into the advanced planning tools described above.

[24] McKinsey & Company, "Decarbonization of Industrial Sectors: The next Frontier," June 2018.

5.2.3. Workforce Development

The NIAC's final suggestion related to efficiency concerns the availability of labor to support and effectively deploy infrastructure during the mass electrification of transportation and other sectors. Several concerns arose in the NIAC's deliberations with respect to workforce development and training requirements to advance the practical application of electrification technologies. Considering these concerns, the NIAC recommends an initiative that:

> **Supports workforce development and energy stewardship as key professional and civic competencies for both new and tenured employees.** This would begin to address the steep learning curve for electrification technologies.

Equitable and inclusive electrification requires the wide dissemination of knowledge about career and business growth opportunities. Early electrification and clean generation opportunities initially targeted affluent consumers, but as prices have come down, those technologies are now available to a much broader range of customers, as are the benefits. Broader electrification will require additional workforce development efforts to increase the number of installers of technology like heat pumps, solar panels, batteries, and chargers. It also presents an opportunity to broaden and diversify the workforce and engage all communities in the clean energy transition, which was by the Rocky Mountain Institute's briefing to the NIAC and in public reports provided by McKinsey.[25] It is widely known that workforce retirement presents many companies with legacy hardware and software and a challenge in maintaining legacy systems. These challenges exist across trade and craft workforces as well. A joint initiative between the Department of Education, the Department of Labor, and the DOE could map out career paths and public needs to accelerate the dissemination of information amidst a generational change in occupational opportunity and fundamental technologies. The focus in this investigation must encompass the labor needed and the quality of the jobs that will emerge to sustain the necessary labor development. Additionally, where possible, continuity should be sought in designing career pivots that utilize specialized expertise in a meaningful way. An example career pivot could be attained by retraining professionals with expertise in well-drilling to develop geothermal resources.

The gold standard of effective program development and administration also requires significant ongoing community engagement. The NIAC emphasizes the need to include communities and trade workers who are impacted by the energy transition to evaluate proposed transition strategies and to assess needs on the ground. Public meetings and active community participation are essential to ensure that workforce programs are relevant and effective.

Electrification presents significant challenges in people readiness; however, these challenges may be overcome with training and education programs. The foundation of these programs is information transparency and meaningful engagement, particularly around key tradeoffs that will help the program to maintain credibility. This credibility will prove more important as the approach begins to engage organized labor, philanthropy, and respected community-based advocacy organizations. Given the potential sensitivities across these organizations, representatives and anticipated participants must be engaged early and often to provide process input.

[25] McKinsey & Company, "Accelerating Decarbonization in the Built Environment Is Essential for a Sustainable Future, but Industry Challenges Need to Be Addressed for Solutions to Scale.," June 12, 2023, 47. https://www.mckinsey.com/industries/engineering-construction-and-building-materials/our-insights/building-value-by-decarbonizing-the-built-environment.

5.3. Security: Managing Threats

The third electrification strategy relates to the information technologies that run legacy and new hardware. Critical digital infrastructure is needed to coordinate grid operations, including advanced distribution management systems, distributed energy resource management systems, energy management systems to coordinate grid-edge operations, and the secure advanced communications bandwidth to provide high volume, low-latency connectivity that supports grid operations. The NIAC recognizes a deep commitment across government and private sector entities to combat cybersecurity threats. The NIAC also recognizes controversy surrounding how foundational grid technologies should be built and maintained. For example, the Energy Web Foundation, an energy transition nonprofit, relies on open-source tools for their technologies. Regardless of the strategy selected, the cybersecurity risk needs to be carefully and exhaustively managed.

Cybersecurity is critical to all sectors of the economy and government, and the NIAC sees value in differentiating between levels of risk to the grid in the performance-based regulations that are adopted. It is essential that practical risks be recognized for technologies, both with respect to isolated and disorganized attacks as well as highly sophisticated and coordinated actions. One of the key initiatives to manage these risks is an increase in grid visibility; however, there are debates on the best method to establish it. Span IO suggested that additional grid devices are needed to refine visibility. In contrast, ChargePoint suggested that uncertainty in grid-edge control can only be managed with improved visibility within utilities' own secure operations. The NIAC recommends an effort, led by the Office of Cybersecurity, Energy Security, and Emergency Response at the DOE, to:

> **Conduct a national cybersecurity assessment of software, hardware, network, distribution, and generation,** with the assistance of the private sector and intelligence agencies tasked with preventing attacks by foreign states.

The NIAC notes the important steps taken in the release of the 2023 ***National Cybersecurity Strategy***, which asserts a strategic objective to "secure our clean energy future."[26] The corresponding ***National Cybersecurity Strategy Implementation Plan*** published in July 2023 tasks the DOE and the Office of the National Cyber Director with developing plans to accelerate clean energy cybersecurity and to establish a cyber-informed engineering strategy, respectively.[27] The NIAC applauds these efforts and encourages additional engagement with grid operators and software designers to advance robust, resilient, and secure smart grid infrastructure.

5.4. Unity: Coherent Policy to Establish Effective Standards

Sustaining and improving grid reliability amidst rapid electrification requires a full range of efficient technologies supported by adequate grid resources that are developed using unified standards and coherent policies. This will be difficult to achieve given the degree of complexity in Federal, state, and local energy policy. There is a need for more unifying policy coordination spanning political boundaries to overcome reliability risk. Concurrently, coordinated policy must be aware of regional differences in grid needs and capabilities. A one-size-fits-all approach to an electrified grid will not adequately account for variation in population density, travel behavior, winter heating needs, building stock, household energy

[26] White House, "National Cybersecurity Strategy," March, 2023. https://www.whitehouse.gov/wp-content/uploads/2023/03/National-Cybersecurity-Strategy-2023.pdf

[27] White House, "National Cybersecurity Strategy Implementation Plan," July 2023. https://www.whitehouse.gov/wp-content/uploads/2023/07/National-Cybersecurity-Strategy-Implementation-Plan-WH.gov_.pdf

budgets, industrial demand, existing clean generation resources, and renewable resource potential. Instead, regional public-private partnerships must undertake the complex and interdependent work of electrification planning.

In the NIAC's briefings, the need for coherent policy and consistent standards ranked among the top priorities the NIAC should address. The NIAC received specific guidance on state-level electrification dialogues from NASEO, which indicated a variety of perspectives and ongoing electrification collaboration. Divergent electrification policies may be difficult to overcome, but a model approach could be sufficient to allow those who do act in the policy space to act consistently. In briefings, coherence was also presented as a practical solution to key challenges in extending grid capabilities to new electrified loads. The end goal is not a unified energy policy that ignores current arrangements, but an increased awareness of the costliest inconsistencies that supports a more coherent regime.

As policy continues to develop and plan for an electrified future, technology innovation will continue to be essential, not only in ensuring that the best technologies are available, but also in ensuring that policymakers fully understand the capabilities, limitations, and costs of these technologies to sustain the cadence of cost-beneficial policy initiatives. As these technologies evolve, some legacy regulatory frameworks and permitting processes may need to be revisited. In turn, market structures must evolve to fully support evolving technologies and needs.

5.4.1. Coherent Transmission Policy Frameworks

> To advance policy-enabling projects across political boundaries in deregulated and regulated markets and to weave together disparate power grids, **establish a task force to identify barriers to multi-state and international transmission project success.**

Long-distance transmission projects rank among the key enablers of growth in clean generation that support near-term electrification, but these projects have proven to be extraordinarily difficult to build. The challenges in building long-distance transmission concern multiple jurisdictional hurdles. If transmission is not built out in advance of grid generation needs, electrification loads have the potential to drive up cost, jeopardize reliability, and/or push resilience to its limit. The NIAC recommends the existing Joint Federal-State Task Force on Electric Transmission consisting of members from FERC and state regulators designated by NARUC specifically focus on issues related to transmission of renewable energy to support increasing electrification and how to overcome challenges related to siting, permitting, and other multi-state barriers to these projects.

5.4.2. Standards Harmonization to Support DER Deployment and Market Participation

> **Convene an inter-agency task force to advance standards for control systems and security enabling the resilience potential of DER and controllable loads.**

The integration of DER at the grid edge, such as rooftop solar and batteries, benefits grid performance. The combined thrust of building efficiency, energy storage, on-site generation, and sophisticated building controllers can significantly reduce a building's impact on the grid and provide resilience benefits to the building occupants. With grid forming inverters and adequate energy storage, a building may be able to serve critical functions during an outage. Bringing down the costs of these technologies requires scale, yet the diversity of regulatory and utility policies requires each company to frequently customize its design and operation. The NIAC was briefed on how over 5,000 companies are now installing products at the grid edge, evidencing an even greater diversity of operational characteristics. This level of complexity can only be managed with a significant degree of grid-edge automation that adapts to conditions while also behaving in a way that is predictable to the utility.

Flexible loads are one of the most significant benefits of the electrification transition. To the extent that smart devices and battery energy storage capacity can shift system peaks, generation and distribution assets can be more efficiently utilized, allowing for the mitigation of total system cost. The current phase of new technology development at the grid edge is moving at an incredible pace. A proliferation of new devices, many of which are establishing their own custom protocols are implementing standard protocols in customized ways. The NIAC heard a persistent concern with a technological "Tower of Babel" that seems to be emerging on the grid edge across different utilities and states. Some challenges are strictly technological, relating to a lack of coherent standards in control functionality, such as controls of HVAC equipment. A taskforce may consider how Energy Star and other ratings may be used to encourage more harmonization on the equipment side. A standards-driven approach can also reduce risk. Translating and customizing control frameworks increases cybersecurity risk by spreading limited IT talent thinly and making it more difficult for developers to push updates that are widely implemented where issues are discovered. The task force, including representatives from CISA, the National Institute for Standards, and Technology, and other relevant agencies, should investigate how best to establish standards and how to discourage the use of legacy protocols that ought to be retired.

5.4.3. Increased consistency in electrification policy

Given the significant variation in state-level policy and the need for coordination with Federal regulators and policymakers that may hinder the standardization of electrification tools, technologies, and markets, **convene a joint working group to incentivize policy harmonization that aligns with both international standardization efforts and state-level initiatives.**

With membership appointed by NARUC and FERC, a state-level policy initiative modeled after the previously mentioned task force on electric transmission could help to identify and prioritize the competing approaches to DER that are hindering mass adoption. In some cases, standards are within reach of technical bodies and only need to be formalized on a consistent timeline across regions. In other cases, new markets and standards are needed to ensure that key mechanisms are available to all grid participants. A consistent regulatory process also promises greater transparency in the way that programs are implemented to support more consistent results. An objective of the task force could be to disseminate the adoption of useful tools and resources more quickly and to refine and standardize the tools that have already been piloted. For example, California has implemented a real-time marginal generation signal to inform self-generation and battery charging cycles. If signals like this are standardized, it is much less expensive for grid-edge devices to use them than it would be if each state developed its own methodology. Span IO explained that this problem can result when different utilities mandate different services that they need, making cybersecurity more difficult to implement. The California Load Flexibility Research and Development Hub (CalFlexHub) is trying to resolve this bottleneck in the state regulatory context through an initiative that was launched to define and refine standards that are necessary to advance grid capabilities.

5.4.4. Emergency Preparedness, Response, Recovery, and Mitigation Coordination

Strengthen standards for information-sharing and coordination between power utilities and Federal, state, local, territorial, and tribal governments for preparedness, response, recovery, and mitigation of power disruptions.

With climate change exacerbating the frequency and duration of power disruptions, more grid-disruptive events are likely. Power utilities need to work in close coordination with Federal, state, local, territorial, and tribal governments in preparing for such events, including planning, training, and exercises. Joint exercises such as GridEx are needed to strengthen the response framework and lessons learned. An important area of joint coordination and response is 360-degree system situational awareness paired with rapid alert and warning capabilities. This has been proven crucial to saving lives. The NIAC notes that the Electric Sector Coordinating Council has convened a wildfire subcommittee that has effectively leveraged face-to-face meetings to ensure efficient information sharing and coordination, and that a similar approach may be applied to the challenges of grid emergency response more broadly. An important role for utilities is to enhance controls and protocols to prevent power equipment from causing wildfires. Resilience measures to recover rapidly after a variety of triggering events need to be implemented in high-risk areas. To avoid incident impacts that exceed the capabilities of recovery resources, communities must stay ahead of climate risk, and electrification impacts must be managed in a similar light. Some electrification technologies, like BEVs, behave differently in a fire or catastrophic incident, relative to internal combustion engine vehicles. Emergency response personnel must plan for these changing uses and ensure that safety training encompasses new technologies.

6. Call to Action

The NIAC met with policy experts, governmental officials, regulators, and others – each of whom identified the criticality today of reliable electricity and the magnified challenges that the nation will face as more and more functions of daily life are electrified. The eleven recommendations contained in this report form a comprehensive starting point to further the dialogue about these challenges among infrastructure owners and operators, policymakers, regulators, and the public. Given the increasing pace of electrification and the centrality of it to the nation's climate goals, the NIAC urges the President to consider these recommendations and move expeditiously to implement them to improve the reliability and resiliency of the American electrical system and the critical infrastructure that rely on it.

Appendix A: Electrification Opportunities and Risks by Sector

CISA Sector	Electrification Opportunities	Electrification Risks
Chemical	Responsible for 24% of global GHG emissions, the chemical sector has recently been identified as a critical opportunity for electrification.[28] Green chemistry[29] processes may become a key source of innovation. Biochemistry innovation in pharmaceuticals provides an illustrative example of an area where electrification is being used for process innovation.	Both batch and continuous chemical production processes are already sensitive to energy disruption wherever thermal cycles and mechanical processes are time sensitive. Long-duration outages could cause cascading effects across industries, and even short outages can be costly. One vegetation-related outage event at Eastman Chemical in Longview Texas had an operational cost of $15 million.[30]
Commercial Facilities	Heat pump electrification coupled with energy efficiency is the principal opportunity for electrification of large buildings, but new technologies for larger scale systems are also under consideration.	High rates of electrification among buildings will eventually lead to winter peaks. This may lead to price spikes because these demand spikes are expensive to mitigate in cold climates since low-carbon energy is in short supply during winter nights.
Communications	Communications infrastructure is already widely electrified. However, the NIAC received a written briefing from Windstream indicating 5G mobile technology will lead to a net increase in electricity demand in the sector due to the relatively larger number of equipment locations required compared to previous network generations.	If the electrification of sectors that are currently more fossil-intensive is poorly managed and outages increase as a result, communications infrastructure may need additional pocket resiliency, such as battery backup support, to sustain service level.
Critical Manufacturing	Processes requiring steam or heat treatment are often reliant on natural gas and may be difficult to electrify, but a significant portion of	Manufacturers often install backup power, which mitigates key electrification risks. Equipment obsolescence and available grid

[28] Kelley Travers, "To Decarbonize the Chemical Industry, Electrify It," MIT News | Massachusetts Institute of Technology, January 31, 2023, https://news.mit.edu/2023/decarbonize-chemical-industry-electrify-it-0131#:~:text=Electrified%20processes%20have%20the%20potential.

[29] Green chemistry is the design of chemical products and processes that reduce or eliminate the generation of hazardous substances. US EPA. 2013. "Basics of Green Chemistry | US EPA." US EPA. February 12, 2013. https://www.epa.gov/greenchemistry/basics-green-chemistry#definition.

[30] Jo Lee Ferguson, "Eastman Reports $15 Million Pricetag for August Outage," Longview News-Journal, November 4, 2019, https://www.news-journal.com/news/local/eastman-reports-15-million-pricetag-for-august-outage/article_f68e02e0-ff39-11e9-a54d-5be29b6d6455.html.

CISA Sector	Electrification Opportunities	Electrification Risks
	manufacturing processes already rely on grid power, and heat pump designs to generate steam are under consideration. Facilities' upgrades to electric heat may become more common.	capacity are risks for planning electrification decisions given unanticipated equipment failure.
Dams	Where available, hydroelectric dams and pumped water storage are robust technologies that can support significant electrification with clean generation.	Where electrification customers look to hydroelectric power or pumped energy storage for firm renewable resources, they must also account for the additional uncertainty of water reservoirs given weather impacted by climate change.
Defense Industrial Base	See critical manufacturing	
Emergency Services	Vehicles with high daily mileage are prime targets for electrification given fuel cost savings benefits. Long-lived vehicles and vehicles where grid access is uncertain are unlikely to be replaced by electric alternatives.	Emergency vehicles risk service disruption amid grid disruptions where these services are needed the most. Risk of service disruption can be mitigated with grid resilience and by maintaining a fleet that includes an adequate stock of legacy internal combustion engine vehicles (ICEV).
Energy	Electrification is a growth opportunity for some energy companies and a business risk for others. All energy companies would benefit from a more stable transition timeline to aid capital investment decisions.	Poorly planned electrification growth, insufficient investment, a failure to support career transitions for changing workforce needs, and insufficient resources to mitigate operational risks like cybersecurity all have the potential to undermine electrification aspects of the energy transition, disrupting all other sectors.
Financial Services	Financial services are already reliant upon electrification.	Like communications networks, financial networks that process transactions require a robust and reliable grid to ensure public confidence in the financial system. If broader electrifications taxes current infrastructure, back-up systems to ensure reliability may be needed.

CISA Sector	Electrification Opportunities	Electrification Risks
Food and Agriculture	Indoor agriculture is one of the areas where increased electrification may be transformative, altering where food is grown, who grows it, and how long it takes the food to reach the people who eat it.	Poor reliability is already serious risk to the refrigerated food supply. As indoor agriculture increases, more food will be grown under conditions that cannot be maintained without grid energy, which adds an additional facet to outage risk.
Government Facilities	See commercial buildings	
Healthcare and Public Health	Healthcare services are already substantially electrified. However, the healthcare workforce (14% of all U.S. workers) is a prime target for workplace charging and resiliency applications of vehicle-to-grid technologies.	Grid outages disrupt all plans and needs, and these disruptions are also correlated with negative health outcomes. Health is an important consideration should grid reliability begin to decline.
Information Technology	Most IT systems are already electrified.	As the generation stack becomes increasingly constrained, energy-intensive IT processes will be competing for resources with a new class of energy loads. To the extent that service level agreements permit more demand response, IT services might benefit from cost savings.
Nuclear Reactors, Materials, and Waste	Nuclear power is uniquely suited for winter peak scenarios that are particularly difficult for intermittent renewable resources to serve.	While electrification does not pose any direct threat to nuclear generation, the uncertainty in adoption timelines makes it more difficult to manage long-term generation resource planning for grid reliability planning.
Transportation Systems	By land, sea, or air, electrification technologies are under consideration across an exceptionally wide range of applications. Operators benefit from fuel savings, air quality improvements, and improved vehicle performance.	Planning for transportation electrification involves the management of significant local and regional risks. The coincidence of a major grid disruption and a peak travel event, such as a hurricane evacuation, exemplifies the kind of complexity that must be managed to limit public risks.
Water and Wastewater	Wastewater treatment presents some opportunities for biogas capture and use, which can reduce plant energy demand.	Water facilities are a critical lifeline that require reliable and resilient power to ensure that communities are able to meet their daily

CISA Sector	Electrification Opportunities	Electrification Risks
		needs. If electrification reduces overall grid reliability, water access disruption is a key risk.

Appendix B: Acknowledgements

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Appendix C: Definitions

Term	Common Definition
Electrification	The replacement of fossil fuel energy sources with electric alternatives to achieve improvements in efficiency, performance, cost, energy sovereignty, air quality, and greenhouse gas emissions.
Energy Poverty	Lack of modern, adequate, affordable, reliable, quality, safe and environmentally sound energy services to support development.
Grid Chemistry	Green chemistry is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances. Green chemistry applies across the life cycle of a chemical product, including its design, manufacture, use, and ultimate disposal.
Grid edge	Comprises technologies, solutions and business models advancing the transition toward a decentralized, distributed and transactive electric grid.
GridEx	Provides the electricity industry, government agencies, and other relevant organizations the opportunity to exercise emergency response and recovery plans in response to simulated cyber and physical security attacks and other contingencies affecting North America's electricity system.
Scope 2 Emissions	Indirect greenhouse gas emissions associated with the purchase of electricity, steam, heat, or cooling.

Appendix D: Acronyms and Abbreviations

Acronym/ Abbreviation	Definition
BEV	Battery Electric Vehicle
CBO	Congressional Budget Office
CFI	Charging and Fueling Infrastructure Grants
CISA	Cybersecurity and Infrastructure Security Agency
CME	Coronal mass ejections
COP	Coefficient of Performance
DER	Distributed Energy Resources
DOE	Department of Energy
EAF	Electric Arc Furnace
EMP	Electromagnetic pulse
EPRI	Electrical Power Research Institute
ERCOT	Electric Reliability Council of Texas
EUI	Energy Use Intensity
EV	Electric Vehicle
FERC	Federal Energy Regulatory Commission
GHG	Greenhouse gas
HVAC	Heating, Ventilation, Air Conditioning
IIJA	Infrastructure Investment and Jobs Act
IRA	Inflation Reduction Act
ISO	Independent System Operators
MPGe	Miles Per Gallon of gasoline-equivalent
NARUC	National Association of Regulatory Utility Commissioners
NASEO	National Association of State Energy Officials
NEVI	National Electric Vehicle Infrastructure
NSC	National Security Council
OSTP	Office of Science and Technology Policy
PSPS	Public Safety Power Shutoff
R&D	Research and Development
RTO	Regional Transmission Organization

Appendix E: References

Andrei, Horia, Costin Cepisca, and Sorin Grigorescu. "Power Quality and Electrical Arc Furnaces." In *Power Quality*, 77–100, 2011. https://www.researchgate.net/publication/221911830_Power_Quality_and_Electrical_Arc_Furnaces.

arpa-e.energy.gov. "Press Release | U.S. Department of Energy Announces $9 Million to Projects Modeling Optimal Deployment for Low-Carbon Intermodal Freight Transportation System," August 10, 2023. https://arpa-e.energy.gov/news-and-media/press-releases/us-department-energy-announces-9-million-projects-modeling-optimal.

Ayyagari, Sneha, Michael Gartman, and Jacob Corvidae. "Hours of Safety in Cold Weather: A Framework for Considering Resilience in Building Envelope Design and Construction." *RMI.org*, 2020. https://rmi.org/insight/hours-of-safety-in-cold-weather/.

BHP. "BHP | a Leading Global Resources Company." BHP, 2022. https://www.bhp.com/.

Briggs, Ryan, and Thomas Fitzgerald. "A Proterra Electric Bus Battery Caught Fire in a South Philly SEPTA Depot." https://www.inquirer.com, November 11, 2022. https://www.inquirer.com/transportation/septa-proterra-electric-bus-battery-fire-philadelphia-20221111.html.

California Public Utilities Commission. "Electrification Impacts Study Part 1: Bottom-up Load Forecasting and System-Level Impacts Cost Estimates," May 9, 2023. https://www.cpuc.ca.gov

California Public Utilities Commission. "Public Safety Power Shutoff (PSPS) / De-Energization." www.cpuc.ca.gov, n.d. https://www.cpuc.ca.gov/psps/.

Center for Climate Resilience and Decision Science at Argonne National Laboratory. "ComEd Climate Risk and Adaptation Outlook, Phase 1: Temperature, Heat Index, and Average Wind," November 21, 2022. https://publications.anl.gov/anlpubs/2022/12/180058.pdf.

Climate Impact Partners. "Climate Commitments of the Fortune Global 500." www.climateimpact.com, September 21, 2022. https://www.climateimpact.com/news-insights/news/climate-impact-partners-releases-fourth-annual-report-climate-commitments-fortune-global-500/.

DOE Office of Energy Efficiency & Renewable Energy, and EPA. "All-Electric Vehicles." Fueleconomy.gov, 2017. https://www.fueleconomy.gov/feg/evtech.shtml.

DOE Office of Energy Efficiency and Renewable Energy. "Alternative Fuels Data Center: National Electric Vehicle Infrastructure (NEVI) Formula Program." afdc.energy.gov, n.d. https://afdc.energy.gov/laws/12744.

DOE Office of Energy Efficiency and Renewable Energy. "FOTW# 1167, January 4, 2021: Median Driving Range of All-Electric Vehicles Tops 250 Miles for Model Year 2020." Energy.gov, January 4, 2021. https://www.energy.gov/eere/vehicles/articles/fotw-1167-january-4-2021-median-driving-range-all-electric-vehicles-tops-250.

DOE Office of State and Community Energy Programs. "Home Electrification and Appliance Rebates." Energy.gov. Accessed September 11, 2023. https://www.energy.gov/scep/home-electrification-and-appliance-rebates.

Ferguson, Jo Lee. "Eastman Reports $15 Million Pricetag for August Outage." Longview News-Journal, November 4, 2019. https://www.news-journal.com/news/local/eastman-reports-15-million-pricetag-for-august-outage/article_f68e02e0-ff39-11e9-a54d-5be29b6d6455.html.Fortescue, n.d. https://fortescue.com/.

GTI Energy. 2021. "Commercial Gas Heat Pumps for Hot Water and A/C: Technical Summary of CEC PIR-16-001." https://www.gti.energy/wp-content/uploads/2021/03/WhitePaper-Commercial-Gas-Heat-Pumps-for-Hot-Water-AC-Demo-Restaurant-Applications_06Jan2021.pdf.

Hellerstedt, John, M.D. "February 2021 Winter Storm-Related Deaths - Texas," December 31, 2021. https://www.dshs.texas.gov/sites/default/files/news/updates/SMOC_FebWinterStorm_MortalitySurvReport_12-30-21.pdf.

Lenoir, Tony, and Aude Marjolin. "Charging up on Battery Energy Storage 101, US Market Outlook." www.spglobal.com, April 25, 2023. https://www.spglobal.com/marketintelligence/en/news-insights/research/charging-up-on-battery-energy-storage-101-us-market-outlook.

Martin, Polly. "'More Economic and More Achievable' | Third Mining Giant Opts for Battery-Electric over Hydrogen in Its Vehicles." Hydrogen news and intelligence | Hydrogen Insight, June 26, 2023. https://www.hydrogeninsight.com/industrial/more-economic-and-more-achievable-third-mining-giant-opts-for-battery-electric-over-hydrogen-in-its-vehicles/2-1-1474582.

McKinsey & Company. "Accelerating Decarbonization in the Built Environment Is Essential for a Sustainable Future, but Industry Challenges Need to Be Addressed for Solutions to Scale.," June 12, 2023. https://www.mckinsey.com/industries/engineering-construction-and-building-materials/our-insights/building-value-by-decarbonizing-the-built-environment.

McKinsey & Company. "Decarbonization of Industrial Sectors: The next Frontier," June 2018.

Minos, Scott. "Saving Money with Electric Vehicles." Energy.gov, September 28, 2022. https://www.energy.gov/energysaver/articles/saving-money-electric-vehicles.

NREL. "Interconnections Seam Study." Accessed September 11, 2023. https://www.nrel.gov/analysis/seams.html.

Office of Governor Janet T. Mills. "After Maine Surpasses 100,000 Heat Pump Goal Two Years ahead of Schedule, Governor Mills Sets New, Ambitious Target | Office of Governor Janet T. Mills." www.maine.gov, July 21, 2023. https://www.maine.gov/governor/mills/news/after-maine-surpasses-100000-heat-pump-goal-two-years-ahead-schedule-governor-mills-sets-new.

Rio Tinto. "Global Home." Riotinto.com, February 27, 2019. https://www.riotinto.com/.

The White House. 2022. "Justice40 Initiative." The White House. 2022. https://www.whitehouse.gov/environmentaljustice/justice40/.

The White House. 2023. "National Cybersecurity Strategy." March, 2023. https://www.whitehouse.gov/wp-content/uploads/2023/03/National-Cybersecurity-Strategy-2023.pdf.

The White House. 2023. "National Cybersecurity Strategy Implementation Plan." July, 2023. https://www.whitehouse.gov/wp-content/uploads/2023/07/National-Cybersecurity-Strategy-Implementation-Plan-WH.gov_.pdf.

Travers, Kelley. "To Decarbonize the Chemical Industry, Electrify It." MIT News | Massachusetts Institute of Technology, January 31, 2023. https://news.mit.edu/2023/decarbonize-chemical-industry-electrify-it-0131

Tschofen, Peter, Inês L. Azevedo, and Nicholas Z. Muller. "Fine Particulate Matter Damages and Value Added in the US Economy." *Proceedings of the National Academy of Sciences* 116, no. 40 (September 9, 2019): 19857–62. https://doi.org/10.1073/pnas.1905030116.

U.S. Congressional Budget Office. "Enhancing the Security of the North American Electrical Grid," March 2020. https://www.cbo.gov/system/files/2020-03/56083-CBO-electric-grid.pdf.

U.S. Department of Transportation. "Charging and Fueling Infrastructure Grant Program | US Department of Transportation." www.transportation.gov. Accessed September 11, 2023. https://www.transportation.gov/rural/grant-toolkit/charging-and-fueling-infrastructure-grant-program.

U.S. EPA. 2013. "Basics of Green Chemistry | US EPA." U.S. EPA. February 12, 2013. https://www.epa.gov/greenchemistry/basics-green-chemistry#definition.

U.S. EPA. "National Vehicle and Fuel Emissions Laboratory (NVFEL)." Greening EPA. Accessed September 11, 2023. https://www.epa.gov/greeningepa/national-vehicle-and-fuel-emissions-laboratory-nvfel.

U.S. EPA. "Scope 1 and Scope 2 Inventory Guidance." U.S. EPA, December 14, 2020. https://www.epa.gov/climateleadership/scope-1-and-scope-2-inventory-guidance.

www.iso-ne.com. "New England's Electricity Use." Accessed September 11, 2023. https://www.iso-ne.com/about/key-stats/electricity-use/#.