2025 ERO Reliability Risk Priorities Report

NERC

NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

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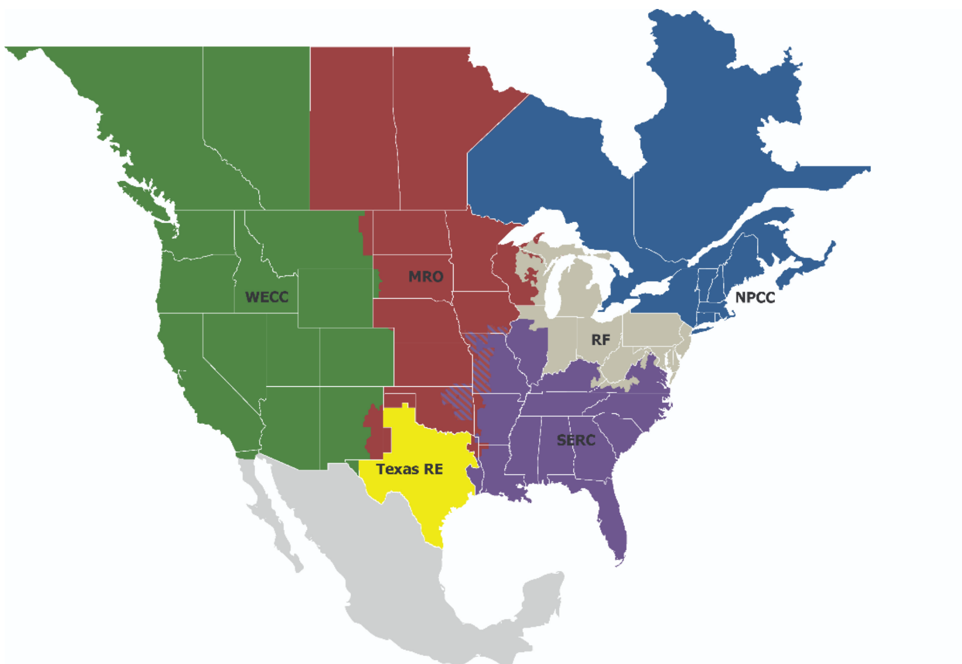
Preface

Electricity is a key component of the fabric of modern society and the Electric Reliability Organization (ERO) Enterprise serves to strengthen that fabric. The vision for the ERO Enterprise, which is comprised of NERC and the six Regional Entities, is a highly reliable, resilient, and secure North American bulk power system (BPS). Our mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid.

Reliability | Resilience | Security

Because nearly 400 million citizens in North America are counting on us

The North American BPS is made up of six Regional Entities as shown on the map and in the corresponding table below. The multicolored area denotes overlap as some load-serving entities participate in one Regional Entity while associated Transmission Owners/Operators participate in another.



MRO	Midwest Reliability Organization
NPCC	Northeast Power Coordinating Council
RF	ReliabilityFirst
SERC	SERC Reliability Corporation
Texas RE	Texas Reliability Entity
WECC	WECC

RISC

The Reliability Issues Steering Committee (RISC)[1] advises the NERC Board of Trustees (Board) and provides key insights, priorities, and high-level leadership for issues of strategic importance to BPS reliability. Additionally, the RISC advises NERC committees, NERC staff, regulators, the Regional Entities, and industry stakeholders to establish a common understanding of the scope, priority, and goals for the development of solutions to address emerging reliability issues. The RISC provides guidance to the ERO Enterprise[2] and industry to effectively focus resources on the most critical issues to improve BPS reliability.

This *ERO Reliability Risk Priorities Report* (*2025 RISC Report*) presents the results of the RISC's continued work to strategically define and prioritize risks to the reliable operation of the BPS and thereby provide recommendations to the Board regarding the approach that NERC, the ERO Enterprise, and/or industry should take to enhance reliability and manage those risks.

The RISC participants include representatives from the NERC committees, the Member Representatives Committee, and "at large" industry executives. The observations, findings, and guidance presented in this report include input from industry forums, trade associations, and other industry groups through multiple channels. The RISC also received feedback through both the 2025 Leadership Summit[3] and the RISC Emerging Risks Survey. This report relies on and extends the comprehensive assessment and corresponding recommendations to the Board made in August 2023 that have been updated and refined. This *2025 RISC Report* reflects subsequent recommendations and will address discussions with representatives from the NERC standing committees and technical reports and assessments conducted by NERC and industry.

[1] Reliability Issues Steering Committee (RISC)
[2] ERO Enterprise is interpreted to mean NERC, the Regional Entities, and NERC's technical committees
[3] 2025 Leadership Summit Program Book

Executive Summary

Introduction

The 2025 RISC Report's primary objectives are to identify key risks to the BPS that merit attention and to recommend mitigating actions that align with those risks; it differs from other NERC reports in that it provides industry with strategic direction to plan for imminent risks and their mitigation. This is in contrast to the State of Reliability or event analysis reports that review data from previous years or events to draw objective conclusions about events, emerging risks, and the appropriate monitoring for their mitigation. This report compliments NERC's Long-Term Reliability Assessment, which is a data-driven assessment of potential future scenarios during the next 10 years.

The 2025 RISC Report reflects the collective opinion and conclusions drawn from RISC membership regarding present and emerging risks and their respective priorities. The RISC assembled and reviewed information from ERO Enterprise stakeholders and policymakers. Focused subgroups then worked to determine and evaluate the current set of risk profiles, added descriptors for each, and recommended mitigating activities. Additional risks and potential mitigating activities were identified during the 2025 Reliability Leadership Summit (Leadership Summit) that NERC and the RISC hosted in February 2025. The Leadership Summit participants were comprised of industry leaders, executives, regulators, policymakers, and subject matter experts with keen perspectives on the inherent and trending risks that affect BPS reliability.

Additionally, the RISC evaluated each risk based on its impact to the BPS regardless of the source or location of the risk. Recognizing that BPS operators and planners require a wide-area view of the system to provide them awareness of external conditions that could affect them, the RISC broadened the risk profiles to include risks associated with grid infrastructure impacting energy deliverability (e.g., telecom and water systems), natural gas delivery systems, and resources located on the electricity distribution system, such as distributed energy resources (DER) and customer distributed resources. Recommendations for potential mitigations of these external risks are also provided.

Critical Risk Profiles

This 2025 RISC Report includes five critical risk profiles:

1. Grid Transformation
2. Resilience to Extreme Events
3. Critical Infrastructure Interdependencies
4. Security
5. Energy Policy

Grid Transformation remains an overarching driver of new reliability risks. Grid impacts emerging from the transformations underway are very different from traditional power system behavioral assumptions, challenging the existing grid's Resilience to Extreme Events. Some events highlight other growing impacts from increasing Critical Infrastructure Interdependencies, particularly between the electric and natural gas systems. Security risk continues to evolve and grow in complication along with the transformations. Energy Policy can further amplify or modify the impact of all of these factors, as policy direction drives transformational timelines, customer and stakeholder behavior, supply chain and workforce developments, regulatory certainty required for adequate investment, and industry attention.

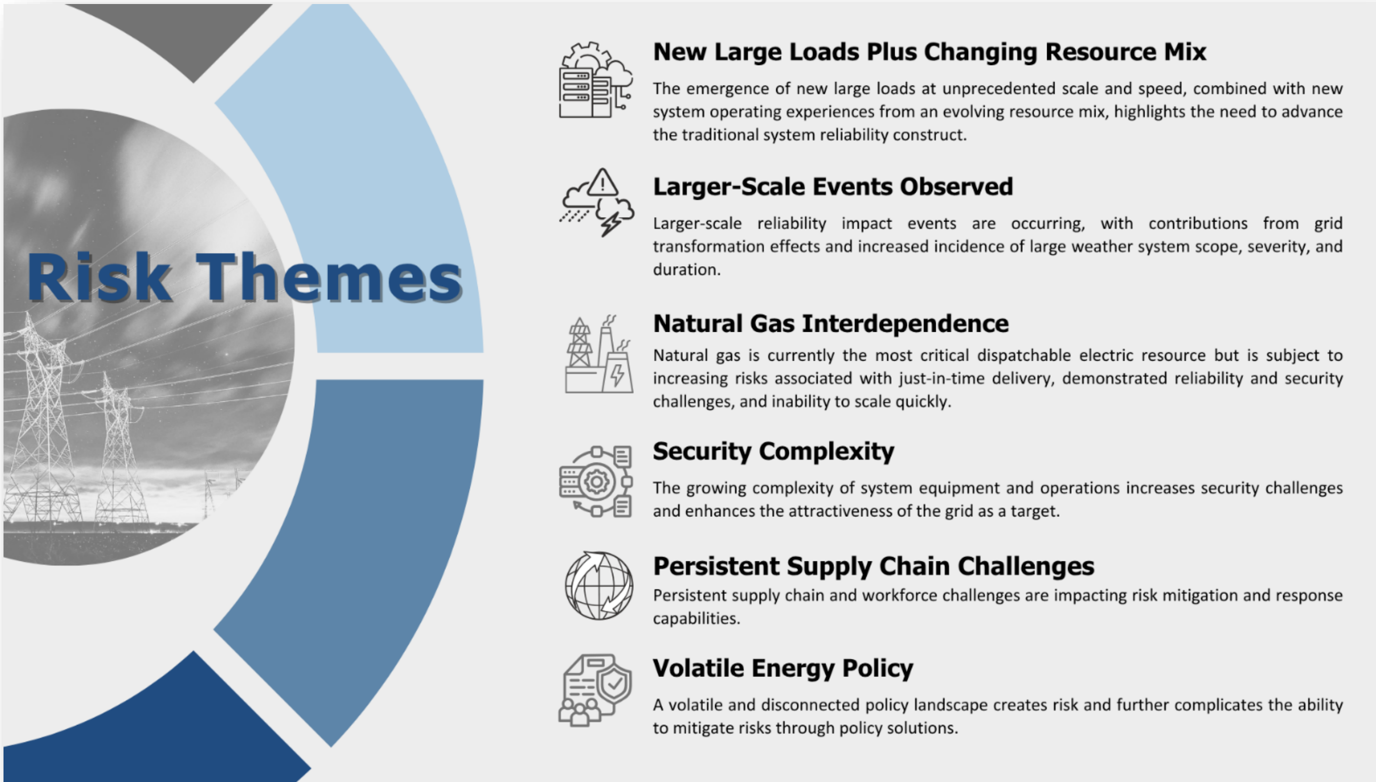
Common Themes and Connections

There are important connections between and among the risk priorities and recommended actions for the ERO Enterprise and industry. While the risk profiles are presented individually, interplay between them compounds the challenge. The RISC recommends that the ERO Enterprise and industry consider these overall themes, the risk profile specifics, and interplay between elements in charting a path to continue active awareness, better understanding, and mitigation of imminent and ever-evolving risks to the BPS

2025Risk Themes

Substantive simultaneous change in all system dimensions (resource, grid, load), along with increasing complexity in the interactions between them, requires rethinking traditional system planning and operating approaches.

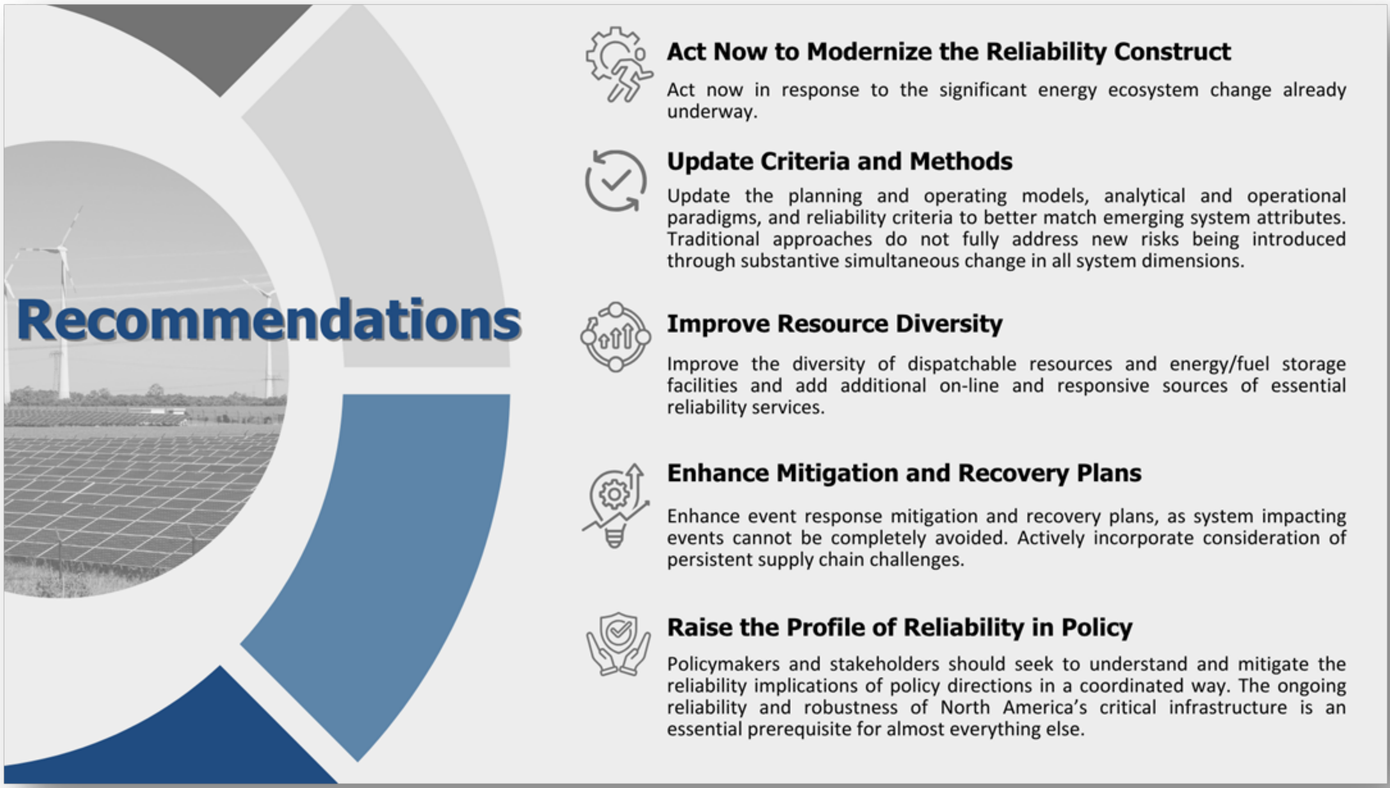
1. **New large loads plus changing resource mix:** The emergence of new large loads at unprecedented scale and speed, combined with new system operating experiences from an evolving resource mix, highlights the need to advance the traditional system reliability construct from capacity to energy based, and more detailed analysis of resources and load centers.
2. **Larger-scale widespread events observed:** Larger-scale reliability impact events are occurring with contributions from grid transformation effects and increased incidence of large, widespread, long-term weather system scope, severity, and duration.
3. **Natural gas interdependence:** The natural gas pipeline infrastructure (natural gas being the primary source of fuel to the dispatchable generation fleet in the next five years) must expand to meet the growing need of these new dispatchable generation units. However, This is subject to increasing risks associated with just-in-time delivery, demonstrated reliability and security challenges, and inability to scale infrastructure quickly. Further, natural gas systems are dependent on just-in-time delivery of electricity. These mutual interdependencies creates an energy interconnection requiring coupled analysis and agreed upon protocols for planning and operations.
4. **Cyber and Physical Security complexity:** The growing complexity of system equipment and operations increases security challenges and enhances the attractiveness of the grid as a target.
5. **Persistent supply chain challenges:** Persistent supply chain and workforce challenges are impacting risk mitigation and response capabilities.
6. **Volatile energy policy:** A volatile and disconnected policy landscape creates risk and further complicates the ability to mitigate risks through policy solutions.



2025 Recommendation Themes

To deliver ongoing system reliability in a time of increasing change and complexity, the following is required:

- More system margin to accommodate uncertainty
- More diverse resource, grid, and operating options
- More awareness of reliability implications of changes
- More comprehensive studies and assessments
- More coordination between impacting parties
- More preparation for large events and restorations
- More speed in implementing necessary measures



The RISC encourages industry to undertake the following recommendations to address the risks identified above.

1. **Act now to modernize the reliability construct:** Act now in response to the significant energy ecosystem change already underway.
2. **Update criteria and methods:** Update the planning and operating models, analytical and operational paradigms, and reliability criteria to better match emerging system attributes. Traditional approaches do not fully address new risks being introduced through substantive simultaneous change in all system dimensions.
3. **Improve resource diversity:** Improve the diversity of dispatchable resources and energy/fuel storage facilities and add additional on-line and responsive sources of essential reliability services. Assess the potential impacts through transmission enhancements.
4. **Enhance mitigation and recovery plans:** Enhance event response mitigation and recovery plans, as system impacting events cannot be completely avoided. Actively incorporate consideration of persistent supply chain challenges.
5. **Raise the profile of reliability in policy:** Policymakers and stakeholders should seek to understand and mitigate the reliability implications of policy directions in a coordinated way. The ongoing reliability and robustness of North America's critical infrastructure is an essential prerequisite for almost everything else.

Background and Introduction

RISC Activities

This 2025 RISC Report documents the results of the RISC's continued work to identify key risks to the reliable planning and operation of the BPS and provide recommendations to mitigate those risks; this includes recommendations regarding priorities to assist the Board and NERC management as well as industry and its stakeholders. The RISC's efforts are both responsive to and in support of the Board's resolutions on the RISC's initial 2013 recommendations. The RISC continues to define and prioritize risks, develop mitigating activities, and identify accountable parties for those risks. The RISC acknowledges and appreciates the increased reliance of the Board and ERO Enterprise leadership on the results of the RISC's activities as an input for the ERO Enterprise's Long-Term Strategy Plan, the Reliability and Security Technical Committee's (RSTC) Work Plan, and NERC's Business Plan and Budget.

Overlapping Risk Profiles

Policy risk areas will overlap with the other risk profiles, and certain themes are repeated throughout this report. There are important links between the risk priorities and the recommended actions for the ERO Enterprise, policymakers, and industry. While the risk mitigation recommendations in each of the risk profiles of this report are presented individually, there are interdependencies acknowledged in this report between many of the risks that present unique challenges to the electric industry. Furthermore, many of these risks have been long recognized with commensurate NERC and industry monitoring for proper mitigation; however, other risks are newly emerging and require active management with a more aggressive immediate approach being necessary for effective foresight and mitigation.

Background and Inputs

Reliability Leadership Summit

On February 27, 2025, NERC and the RISC hosted the Reliability Leadership Summit (Summit) with leaders of the reliability and security community, including top industry executives; state, provincial, and federal regulators; and ERO Enterprise senior leadership. The summit focused on three specific areas: Grid Resiliency, Security, and Energy Policy. An open panel discussion was held at the end of the day for industry leadership to address "what keeps you up at night." This panel session inspired a robust discussion of issues and risks facing industry and the grid.

The panel discussions underscored the importance of conducting cross-sector coordination with other industries and covered the transformation of the grid; reliability and security impacts and considerations; lessons learned and unique challenges posed by cyber and physical security risks, their evolution, and potential impacts that could cause damage; and implications of the increased critical infrastructure interdependencies and how to address the jurisdictional issues that need to be tackled to address the risks they present.

2024–25 RISC Emerging Risks Survey

For the 2025 report, the RISC issued the Emerging Risk Survey in two phases. The first phase was conducted December 22, 2024, through January 17, 2025, and contained a list of risks and asked stakeholders to identify their top five risks from the list and identify additional risks not on the list for consideration by the committee. The top five risk categories from the original list are as follows:

1. Grid Transformation
2. Cyber Security Vulnerabilities
3. Resource Adequacy and Performance
4. Energy Policy
5. Resilience to Extreme Natural Events/Extreme Events

Followed closely by the following:

1. Critical Infrastructure Interdependencies (e.g., natural gas, electric, water, communications)
2. Large Loads (e.g., data centers, crypto mining)
3. Supply Chain Capacity

Many commenters provided suggestions for combining risk areas for further evaluation. These risk profiles are in no particular order or ranking of priority, identified as follows:

- **Grid Transformation** (More inverter-based resources, fewer large synchronous generators, more advanced electronic devices like static var compensators, aggregators, IBR-GO/GOP), increased distributed energy resource (DER) and demand-response use, electrification (e.g., heat pump load)
- **Cyber Security Vulnerabilities** (e.g., operations technology, energy management systems, IT systems, large loads, DERs and DER aggregators)

        - Supply Chain Capacity
        - Cyber System Vulnerabilities
        - Physical Security Vulnerabilities (transmission and generation infrastructure protection)
        - Resilience to Extreme Natural Events/Extreme Events (e.g., hurricanes, tornadoes, wildfires, derechos)
- **Resource Adequacy and Performance (e.g., energy assessments)**
    - Large Loads (e.g., data centers, crypto mining)
    - Electric Vehicle Impacts (e.g., charging, load shape changes due to electric vehicle (EV) activity)
    - BPS Planning (e.g., energy availability assessments, IBR/(electromagnetic transient (EMT) modeling, capacity evaluations)
- **Energy Policy** (e.g., IBRs, EV mandates)
- **Critical Infrastructure Interdependencies** (e.g., natural gas, electric, water, communications)

The phase one survey also included an opportunity for respondents to identify emerging risks that were not on the list provided. Key emerging risks include public resistance to infrastructure development, affordability challenges, lack of financial resources for maintenance, governance issues for AI, disruption of cloud services, and inaccuracies in modeling generation and transmission. Other noted risks involve increased compliance burdens, climate change impacts, and the need for improved energy storage utilization. The survey also highlights the importance of considering cost/benefit evaluations in grid transformation and the risk of retiring conventional generators prematurely. Respondents emphasize the significance of education on electricity use and the necessity of streamlined regulatory processes for infrastructure development.

Phase two of the survey was issued January 24–February 14, 2025. The focus of this survey was to confirm the top-five risk areas identified in the phase one survey.

Participants provided their opinions on the rankings of the top five emerging risks in the industry. These risks include grid transformation, cyber security vulnerabilities, resilience to extreme natural events, resource adequacy and performance, and energy policy. Responses varied with some agreeing with the rankings and others suggesting adjustments, such as elevating the importance of resource adequacy or resilience to natural events. Participants also highlighted the interconnectedness of certain risks and suggested grouping related categories or reconsidering how specific risks are addressed. Overall, there is consensus on the importance of these risks, though opinions differ on their prioritization.

The top five risk areas that the RISC has selected for full discussion in the report are **Grid Transformation**, **Security**, **Resilience to Extreme Events**, **Energy Policy**, and **Critical Infrastructure Interdependencies**. The RISC considers these risk profiles equally impactful to the reliability, security, and resilience of the grid.

Stakeholder Comments

The report was posted for stakeholder comment on **July 7, 2025**, and the comments received were reviewed and incorporated as applicable.

Risk Profile #1: Grid Transformation

Statement of the Risk

Grid transformation remains a significant risk to the reliable operation of the electric system as new large loads change the landscape of customer demand from organic population-driven growth to rapid investment-based deployment of data centers (including hyperscalers[4], AI centers, and cryptocurrency) and large manufacturing. Inverter-based and natural gas resources continue to replace retired conventional thermal generation but not at the rate of retirement. Furthermore, IBRs' operational characteristics differ from those of the retiring thermal generation. As limited energy resources become more prevalent on the grid, resource adequacy and energy sufficiency remain top of mind throughout the year, especially during extreme conditions.

This report has continued to point out the evolution of these risks over its last few iterations. The efforts that NERC and industry continue to undertake are paramount to keeping the U.S. power grid "the greatest engineering achievement of the 20th century." Efforts that require continued focus include the following:

- **Growing Demand**: Large loads and enhanced needs for flexibility will significantly influence grid transformation. Multiple factors, including data centers (including hyperscalers, AI, and cryptocurrency), onshoring of manufacturing activities, electrification of industrial processes, and commercial and residential electrification, are contributing to demand growth. Many of the large digital loads in question require more detailed modeling and control coordination to ensure reliable integration. These trends are also increasing attention on backup power systems, co-location of loads with existing or new generation, and additions of generation and storage behind the transmission point of interconnection or distribution system meter.

- **Changing Resource Mix:** There is an ongoing need to rethink the usefulness and meaning of Planning Reserve Margins as utilities contemplate integrated resource planning. Namely, energy measures (including time and impact parameters) representing the growing presence of energy constrained resources can provide deeper understanding of risk levels and resource solutions. There is an opportunity to enhance Planning Reserve Margin methodologies. The variable nature of generation profiles with more IBRs is more accurately represented using energy availability patterns.

- **Interconnection, Modeling, and Grid Management Systems**: Connecting our planning processes across the Interconnections requires consistent perspectives around capacity assessment and how coordinated operations can enhance reliability. Utilities and generation owners need to validate modeling assumptions when connected to the grid, and throughout the life of assets, to promote system stability. Integrated modeling approaches that span transmission

[4] Hyperscale Computing is necessary in order to build a robust and scalable cloud, big data, map reduce, or distributed storage system and is often associated with the infrastructure required to run large distributed sites such as Google, Facebook, Twitter, Amazon, Microsoft, IBM Cloud or Oracle Cloud… Such companies are sometimes called "**hyperscalers**."

and distribution provide comprehensive visibility into system behavior under various conditions. By evolving grid modeling data and systems, planning accuracy and operational efficiency can be improved.

- **Supply Chain and Security Risks:** The deployment of new generation to address reliability and resource adequacy is increasingly constrained by supply chain disruptions affecting critical components. Global shortages of raw materials, manufacturing bottlenecks, geopolitical trade policies, and transportation delays have significantly extended lead times for new generation procurement, assembly, and installation. In addition to generation equipment constraints, high-voltage transformers have persistently faced long lead times, posing challenges to all sources of generation. Further, sources of equipment and components need to be understood to estimate potential risks and their mitigation when the equipment is integrated into the BPS.
- **Integrating Energy Storage Technologies:** Energy storage can provide flexibility for balancing system needs across multiple time frames, from frequency regulation to peak shifting. By developing compensation models and control systems that recognize the full range of storage capabilities, reliability can be cost-effectively enhanced while the integration of variable resources is supported. Thoughtful implementation of storage solutions represents an opportunity to enhance system resilience while potentially creating new value for customers. One of the primary challenges will be the move to incorporate the energy measurement of limited-duration resources into the dashboards and metrics (traditionally based on power measurements) that are used to monitor the grid.
- **Essential Reliability Services:** The foundational services that ensure grid stability—frequency response, voltage support, and ramping capability—benefit from performance-based definitions that encourage innovation across technologies. However, availability and deployment of these essential reliability services may become less certain, especially during long-term, widespread system conditions. By evolving our approach to these essential reliability services and market incentives to perform them, system stability can be maintained even while new resource types that bring valuable capabilities to the grid are welcomed. This inclusive approach creates pathways for reliable operation while supporting beneficial technological advancement.

Descriptors of the Risk

1. **Large Loads and Electrification ("Large Loads")**

   Growing demand and enhanced needs for flexibility will significantly influence grid transformation. Multiple factors, including data centers (including hyperscalers, AI, and cryptocurrency), onshoring of manufacturing activities, electrification of industrial processes, and commercial and residential electrification, are contributing to demand growth. Some of this load is asynchronous to the grid and digital, creating system conditions and ride-through challenges during system events. Integrating these large loads and viewing them as BPS resources for flexibility and reliability contribution, when possible, will be challenging but crucial.

   These challenges provide substantial opportunities to deploy important grid enhancements. For example, the scale, value, and design of data center loads may provide flexibility through backup power systems, energy storage, and demand-side flexibility while also encouraging innovation and investment in longer-duration energy storage, emerging resources, such as small modular reactors (SMR), and novel designs of energy parks that can also contribute essential reliability services and energy when most needed.

2. **Resource Adequacy and Energy Sufficiency – Traditional Planning Reserve Margins are no longer sufficient ("RA")**

   Resource adequacy assessments have historically focused on ensuring generation and transmission capacity to serve peak demand with the assumption that this would be adequate to meet demand in all other hours of the year. Recent extreme events have demonstrated that assessments must look beyond this assumption, considering the magnitude, duration, energy sufficiency, and customer impact across all hours and many years. These assessments must also consider that future events may be outside of historical patterns, such as environmental impacts on resource availability, while also accounting for contributions from load resources, transmission resources, and neighboring grids. Furthermore, the pace of resource retirements is exceeding the addition of new capacity while load looks poised to grow substantially, and resources on the path to retirement may not be able to perform at the assumed levels of availability, flexibility, and reliability. Enhanced and coordinated planning for the long-term planning, operational planning, and operating time horizons will be essential.

3. **Interconnection and Modeling ("Interconnection and Modeling")**

Interconnection requirements are not consistent across regions or entities and may lack performance and modeling requirements with adequate specificity, leading to undesirable performance of resources and harmful ambiguity for prospective resource owners (including large flexible loads, IBRs, and storage). Detailed information on equipment characteristics, capabilities, settings, and limitations must be incorporated into the long-term planning, operational planning, and operating time horizons. This is particularly true for digital controls, IBRs, and power electronics-based loads and resources more broadly. Even when a useful equipment standard exists, such as the IEEE 2800 standard for future inverters connecting at transmission voltages, the system planner must specify the parameter settings for the desired performance characteristics for a given resource, the resource operator must set the parameters accordingly, the commissioning process and performance monitoring must be able to verify the desired operation of the resource, and the operator must verify that settings are maintained through the operating life of the asset.

Parallel development of control systems and operational models should match the pace of innovation with continued progress on Federal Energy Regulatory Commission (FERC) Order No. 901 (Reliability Standards to Address Inverter-Based Resources) essential for the interconnection and modeling of IBRs, and similar considerations likely to be necessary for large power electronics-based load, such as data centers. Furthermore, while FERC Order 901 refers to "standard library models" (parameterized generic models), these can be insufficient to fully reflect equipment responses—user-defined models should more accurately represent equipment responses and keep pace with the innovation of the original equipment manufacturers (OEM). Furthermore, system dynamic performance will be challenged with the growth of IBR, potentially showing the need for new model development supporting advanced system design and the development of new EMT models to reflect equipment responses.

4. **Growing Supply Chain and Development Uncertainties ("Supply Chain")**

Many issues must be coordinated to speed the completion of new resources so that their reliability contributions can benefit the BPS. Lead times for fuel sourcing and other elements of resource adequacy (e.g., transmission development, generator retirements, pipeline construction, environmental permitting, right-of-way acquisition) may require long and/or uncertain lead times. Various elements must be carefully sequenced to ensure reliability throughout transitions, and the interrelated nature and contribution of transmission, generation, and fuel sources must be appreciated and considered in resource adequacy assessments, timelines, and deployments. Large load growth from data centers and domestic manufacturing will exacerbate the need for network upgrades and new resources, and uncertainty around supply chains, international trade, import tariffs, and country restriction issues are disruptive to plans and schedules. Cyber security concerns also remain a consistent and growing risk and are discussed elsewhere (reference - Risk Profile # 4 – Security).

The ability to deploy new generation resources is critical to ensuring energy sufficiency under high-load conditions. Without timely deployment, system operators face increased risks of energy shortfalls, transmission congestion, and reserve deficiencies, particularly during peak demand periods and extreme weather events.

5. **Benefits of Improved Interregional Connection** (**“Interregional”**)
Resource planning, resource adequacy assessments, and operating practices have been constrained by political or utility boundaries that do not fully exploit the benefits of the interconnected BPS as documented by extreme events. Regional planning assessments are currently performed in collaboration with neighboring regions; however, these assessments could be improved by adding additional focus to the benefits of interregional transmission and cooperation between and across regions as an energy resource during critical resource shortage conditions. To maximize these benefits, interregional coordination of strategic transmission and generation additions, permitting, siting, and operations should be optimized to the greatest extent possible.

6. **Grid Management System and Modeling Gaps (“Software Platforms”)**
Technological innovations of resources and systems of resources continue to outpace grid planning models, operation planning models, and real-time grid management software. In some cases, new resource types and technology may be delayed or even prohibited from interconnecting even though their services would be useful to the grid because legacy grid management and market software platforms are onerous and expensive to update. These issues are particularly prevalent for grid-forming inverter technology, hybrid plants that combine different resource types with a unified controller, more complicated resource connections behind a single point of interconnection, and co-located generation and large load projects.

The reliable, widespread interconnection of new resource technologies will require parallel development, demonstration, and innovation in grid management software and operational/planning models at a pace that is comparable to the innovation rate of emerging technologies. This can be difficult to accomplish with legacy grid management systems and may require innovative rethinking of roles and responsibilities of market participants and the system operator. In fact, industry roles with research and development must expedite the demonstration and piloting phases to quickly and reliably interconnect new technologies to keep pace with the innovative applications of energy. Legacy grid-management platforms should be supplemented by additional modern datasets and analytics that provide high-veracity insights improving grid situational awareness. When combined into one interconnected grid, the interactions between increasing numbers of separate new resources and load control systems with their varying operating characteristics may also create new system risks and analytical complexities.

7. **Integrating Energy Storage Technologies (“Storage”)**
Energy storage technologies are transformative to established power system modeling practices, markets, and operational tools and procedures because they do not fit into traditional approaches for generation, load, and transmission. Battery energy storage systems (BESS) can provide a wide range of essential reliability services (e.g., fast-ramping capability, frequency response, and dynamic voltage control), often more quickly and accurately than conventional resources. However, these resources are energy-limited, which can introduce complexities accounting for and assuring that these services are available under relevant operating conditions.

New methods for assessing the benefit, opportunity costs, and state-of-charge optimization strategies to maximize the use of these resources are still being developed and understood. Storage solutions continue to transform both the distribution system and the BPS, in the long-term planning, operational planning, and operating time horizons, and many regions are actively pursuing surplus interconnection services to more fully use existing generator interconnections. This continues to unlock opportunities for faster additions of BESS or other resources that provide reliability benefit to the BPS.

Whether in combination with renewable or conventional resources, and whether connected to distribution systems or the BPS, storage and hybrid technologies will further magnify the pace of innovation and the evolution of resource capabilities during both steady-state and transient conditions. Furthermore, grid-forming (GFM) technology in BESS is a particularly cost-effective grid-stabilizing solution that supports system stability. While equipment standards for GFM inverters are still under active development, and until the impact of GFM inverters on the distribution system are better understood, GFM inverters for battery storage systems are deployed globally5 and their use should be encouraged.

8. Deeper Understanding of Essential Reliability Services and Newer Technologies ("ERS")

Industry is aware of the need for essential reliability services (ERS) and other ancillary services for the reliability and stability of the power system, including the need for voltage control and reactive support, frequency response, ride-through, ramping/balancing, and other stability services. NERC has defined these services and reported on their importance to the health of the BPS in its State of Reliability report.6 Transformation of the resource mix can alter the provision of these ERSs. IBRs are today deploying improved capabilities, and the IBRs of tomorrow will bring enhanced capabilities with GFM functionality. The grid-supporting capabilities and potential interactions of all technologies and resources (including conventional resources, IBRs in their grid-following and GFM versions, and loads) need to be understood to accurately include them in planning and operating analyses. This is further complicated as large loads with flexible operational backup and inverter-based characteristics can impact, and consume, large amounts of these ERSs. Restoration services, such as blackstart capabilities and procedures, must also be considered. For services that may become scarce in the future, both organized and bilateral markets must anticipate and procure sufficient services to ensure reliable operations. There is potential that these ERSs are evolving in a transformed grid and need to be redefined and enhanced.

9. Consideration of Weather, Forecasting, and Combined Effects ("**Forecasting**")

While weather has always affected energy demand, generation, and BPS operations, the increasingly interrelated and combined effects between resources, fuel supplies, and extreme events now make it critical to incorporate high-quality weather forecasts and datasets into modeling, scheduling, and operations in all time frames to ensure BPS reliability. Weather impacts on generation and fuel supplies remain a work in progress with NERC Reliability Standards focused on generator winterization. New plans for additional gas-fired generation may exacerbate known challenges during extreme weather conditions from reductions of natural gas production/transport, availability of gas when needed for power generation, and conflicting uses between electric generation and for heating and other customer needs. At the same time, weather affects production from solar and wind resources whether on the transmission system or distribution system or in combination with industrial complexes, data centers, or storage resources. Traditional analytical methods may not fully account for system characteristics associated with the interactions and uncertainties of the increasingly diverse system of resources and customers, particularly under extreme events or contingencies or when faced with resource, energy, or transmission insufficiencies in the operational horizon. These challenges need to be addressed in the planning and operational planning time horizon to address energy limitations in anticipation of extreme weather and its impacts.

10. Coordination and Aggregation of DERs with the BPS ("DER")

DERs—including generation, storage, and flexible loads with behind-the-meter DERs and other IBR technologies—currently meet local distribution utility interconnection requirements and operational protocols but may pose potential challenges to the BPS in aggregate from a forecasting, planning, cyber, and operations perspective. With the implementation of FERC Order 2222 and growing prevalence of DER aggregators and virtual power plants (VPP), the historically passive unidirectional distribution system is becoming increasingly active and involved in providing core grid reliability services, and enhanced coordination between BPS owners/operators (i.e., NERC registered entities) and distribution utilities and DER/VPP operators is needed.

[5] See https://www.esig.energy/benefits-of-gfm-bess-project-team/

[6] See State of Reliability Report

Certain challenges with DER aggregation could be exacerbated by large flexible loads, particularly if the DERs are connected through distribution interconnection processes due to utility jurisdictional rights under state law rather than through NERC registration and standards applicability. Visibility, control, and performance of aggregated DERs may be needed to ensure planning and operations situational awareness and overall BPS reliability.

11. **Human Performance and Skilled Workforce Adequacy Concerns ("Workforce")**
The BPS continues to evolve in complexity. The industry faces significant risk in staffing skilled workers due to new complexities, advanced technologies, the convergence of engineering and IT skillsets, and competition from other industries. As an example, the industry faces a lack of skilled and experienced talent for EMT studies and models, which are essential for ensuring future grid stability, redundancy, and resiliency as new technologies are interconnected to the grid.

The industry must address human performance and skilled workforce adequacy risks related to long-term development approaches, education, multi-faceted skillset requirements, and technology-related developments to achieve a workforce capable of navigating the grid transformation.

Recommendations for Mitigating the Risk

The table below lists the recommendations and draws from information in the *2023 ERO Reliability Risk Priorities Report*, the expertise of RISC members, and industry comments and feedback and aligns with efforts that are underway or starting up, including the following:

- ESIG Large Loads Task Force[7]
- ESIG Current and Completed Task Forces[8]
- NERC Essential Reliability Services Task Force Measures Framework Report[9]
- NERC 2024 State of Reliability Report[10]
- EPRI DCFlex[11]
- NERC RSTC Large Load Task Force[12]

Recommendation	Timeframe	Interdependency	Risk Addressed
1. <u>Get ahead of large load deployment</u>: **NERC's Large Loads Task Force should collaborate with the Data Center Coalition, the Electric Power Research Institute (EPRI), the Energy Systems Integration Group (ESIG), the North American Transmission Forum (NATF), North American Generator Forum (NAGF) and others to identify the risks associated with large loads, including possible mitigations, and optimize their potential to provide flexibility through backup generation and demand response.** Growing demand and enhanced needs for flexibility will significantly influence grid transformation. Given that large loads, particularly data centers, are driving the increasing	Near Term	RA, Interconnection and Modeling, Software Platforms, ERS, Forecasting	Large Loads

[7] ESIG Large Loads Task Force
[8] ESIG Current and Completed Task Forces
[9] NERC Essential Reliability Services Task Force Measures Framework Report
[10] NERC 2024 State of Reliability Report
[11] EPRI DCFlex
[12] NERC RSTC Large Loads Task Force

Recommendation	Timeframe	Interdependency	Risk Addressed
demand, NERC should establish strategic partnerships to ensure effective coordination with industry efforts. This collaboration could result in technical workshops, white papers, or reliability guidelines to support industry stakeholders as they interconnect more large loads.			
2. <u>**Revisit Essential Reliability Services:**</u> **NERC should revisit ERSs to consider the ongoing growth of power electronic-based resources (including IBRs and some large loads) and the use of GFM inverters with storage as vital and increasingly dispatchable sources of services**. As noted throughout this section, grid transformation is driving the use and integration of IBRs, new types of digital and asynchronous large loads, large-scale storage, and other components not traditionally part of the BPS. This will have an impact on existing reliability services and may necessitate an expansion/identification of new reliability services that push beyond the traditional capabilities of conventional resources into what is possible and beneficial in the future. Building on FERC Order 901 and related Reliability Standards projects, we recommend that a list of grid-transforming technologies with reliability impact should be formally enumerated with a mapping to the reliability services view, improvements to encourage the deployment of useful capabilities, and software platform enhancements to exploit the new capabilities. This should also include recommendations for any new reliability services, both those providing system-level services and locationally specific service needs, to encourage the practical deployment of new capabilities.	Near Term	Interconnection and Modeling, Supply Chain, Software Platforms, Storage	ERS
3. <u>**Further enhance consistent interconnection requirements for all generators, loads, and storage**</u>: **While NERC and industry are making good strides for interconnection of IBRs, NERC should further encourage consistent, enhanced modeling and interconnection requirements for all generators and loads to ensure that equipment characteristics, capabilities, settings, and limitations are incorporated in the planning and operations (and maintained through the life of the asset).** Consistent IBR interconnection requirements should be clearly identified in interconnection agreements. NERC should leverage industry efforts, such as adoption of ongoing NATF work on IBR interconnection lifecycle guidelines to assist BPS operators in this area. To ensure that IBR plants are meeting the performance requirements during the normal operation and after any plant modification (hardware/firmware update), it will be critical to have real-	Near Term	ERS, Supply Chain	Interconnection and Modeling, Large Loads

Recommendation	Timeframe	Interdependency	Risk Addressed
time IBR plant performance monitoring to confirm that plants are meeting interconnection requirements and maintaining reliable operation to support the BPS. Further, for continued reliable operation of the existing IBR fleet connected to the BPS, grid operators may need to grant interconnection amendments to allow for coordination between grid operators and Generator Owners on compliance with upcoming NERC Reliability Standards from FERC order 901 directive.			
4. **<u>Encourage further efforts for interregional planning</u>: NERC's Interregional Transfer Capability Study is a high-level initial step, but further steps should be pursued to enhance interregional and integrated planning of transmission, permitting, siting, and operations.** The next step in enhancing interregional transfer capability (ITC) planning and producing actionable results is to consider the development of metrics that guide transmission decisions by addressing critical factors, such as reliability need, cost-effectiveness, RA contributions, and feasibility. These metrics should guide planning entities in evaluating the benefits of transfer capability enhancements compared to alternatives like the types of generation needed, demand-side management, and operational measures, while focusing on improving reliability and resilience under extreme weather conditions. By increasing transparency and respecting regional differences, this process can support informed decision-making without imposing rigid, one-size-fits-all mandates and would leverage the expertise of planning entities responsible for transmission reliability and resource adequacy. Interregional transfer capacity maximizes effectiveness to improve reliability if it can be utilized during extreme events. This transfer capability, though, can be used to hone a more Interconnection-wide resource plan. Recent occurrences, such as Winter Storm Elliott, have demonstrated that even with existing available ITC, resource adequacy remains a risk to reliability.	Mid-Term	RA, ERS, DER	Interregional
5. **<u>Leverage the capabilities of storage</u>: NERC and other entities (e.g., ERCOT) should educate industry on energy storage solutions to identify system services that enhance flexibility and resilience from this technology. Planners need to begin including these benefits in operating models**. Recent experience in ERCOT shows that battery storage is a dispatchable resource with rapid deployment	Near Term	ERS, RA, Software Platforms, Interconnection and Modeling, DER	Storage

Recommendation	Timeframe	Interdependency	Risk Addressed
and substantial contributions to the capacity, flexibility, stability, and ERS needs of the system. Standalone or in combination with other IBR or conventional resources, battery storage is becoming a vital component of grid transformation. ERCOT and MISO are about to require GFM inverters for new battery storage resources, which have been shown to further enhance the system benefits and reduce the need for some transmission reinforcements. NERC should encourage other system operators to learn from their experience. Battery storage, when viewed at the system level or when hybridized with other generation and/or load resources, is much more than simply a means to shift energy in time and provides underappreciated benefit and positive impacts.			
6. **<u>Enhance resource adequacy and energy sufficiency methods</u>: NERC and industry should consider, and deploy in reliability assessments, resource adequacy methods that better account for real-time operational needs under a wide range of possible scenarios and events.** NERC should also engage with industry for a working group focused on best practices for weather forecasting and the environmental condition impacts on both resources and demand and then use these best practices to inform the planning, operational planning, and operations time frames. Resource adequacy approaches based on Planning Reserve Margins are no longer sufficient with recent events showing that assessments must look at magnitude, duration, energy sufficiency, and customer impact across all hours and many years. The fundamental purpose of resource adequacy programs is to ensure real-time reliability, yet traditional resource adequacy approaches may focus on capacity reserves without accounting for real-time operational needs. Particularly in a future with growing levels of sophisticated loads and diverse resources (including power electronics-based resources and combinations), starting with a real-time reliability perspective and moving beyond traditional supply-side assumptions may be better suited to managing emerging resource adequacy planning challenges. Increasingly, interrelated and weather-driven effects between resources and fuel supplies also make it critical to incorporate high-quality weather forecasts and datasets into planning, scheduling, and operations while considering extreme events, contingencies, and resource, energy, or transmission insufficiencies that could occur in real-time operations.	Near Term	Large Loads, Forecasting, Interregional	RA

Recommendation	Timeframe	Interdependency	Risk Addressed
7. <u>**Develop workforce**</u>**: NERC and industry should place a strategic focus on the development of the workforce for the future.** This includes proactive measures to mitigate risks associated with limited availability of skilled resources and the evolving technical nature associated with grid transformation and modeling. Risk mitigation strategies should include partnerships with trade schools, universities, K–12 engagement, teachers, and technical institutions to build a supply of capable talent along with establishing continuous learning and upskilling development programs to retain and retrain talent.	Mid-Term	Skills needed across all descriptors of risk	Workforce
8. <u>**Move to integrated planning of transmission, generation, storage, and loads**</u>**: Transmission planning must align with evolving resource adequacy assessments to address the growing mismatch between generation deployment timelines and load growth.** Implementing scenario-based planning approaches that incorporate supply chain constraints can help stakeholders develop contingency strategies, reducing uncertainty and delays in bringing new resources on-line, and exploit storage to compensate for delays in transmission and generation deployment. Furthermore, improved coordination between Reliability Coordinators and Balancing Authorities, state and federal regulators, and developers will ensure that generation and transmission projects are sequenced appropriately, preventing misalignment that could lead to grid congestion or inadequate reserve margins. By integrating improved forecasting tools, refining interconnection processes, and aligning transmission expansion with anticipated demand growth, the grid can maintain reliability despite supply chain disruptions and the accelerated pace of electricity demand.	Mid-Term	Large Loads, RA, Supply Chain, Storage, Forecasting	Interconnection and Modeling, Forecasting
9. <u>**Improve load forecasting methods**</u>**: There should be an industry-wide focus on improving forecasting and coordination within the Reliability Coordinator/Balancing Authority and transmission planning processes, particularly regarding large load additions.** Enhancing long-term load forecasting methods to account for rapid demand growth will allow for more proactive infrastructure planning, helping system planners better anticipate generation and transmission needs. Specifically, load forecasting methods must evolve to accurately reflect the range of expected demand increases in the mid and long term, when firm contracts or financial commitments for new AI-driven demand cannot be relied upon. Balancing Authorities should streamline interconnection and study	Long Term	Large Loads, RA	Forecasting, Interconnection and Modeling

Recommendation	Timeframe	Interdependency	Risk Addressed
processes to reduce bottlenecks, ensuring that delays in approving new generation do not exacerbate reliability risks.			
10. **Adapt to the realities of supply chain for near-term resource and transmission needs**: **To reduce the impact of supply chain disruptions on new generation deployment while addressing surging data center demand, industry and policymakers should prioritize facilitating the full suite of generation and storage options while optimizing the existing assets on grid and explore resources that do not face supply chain constraints in the near term or grid-enhancing technologies that can provide immediate available transmission capacity**. New resource development timelines and costs are significantly threatened by an unprecedented confluence of risks and uncertainties in supply chains, tariffs, cyber security requirements, workforce limitations, and general business risk.	Mid-Term	Workforce, RA, Interconnection and Modeling, Storage, DER	Supply Chain
11. **Use demand-side management (DSM) as a mainstream resource: DSM requires a holistic consideration for system planning and accommodation in various energy markets and their role in enhancing grid reliability and resilience.** As many Reliability Coordinators and Balancing Authorities have advanced demand-side management programs that are still evolving and growing at a rapid scale, it is prudent to tap into those features going forward considering the digital nature of the power grid.	Mid-Term	RA, Large Loads, Software Platforms	DER

Risk Profile #2: Resilience to Extreme Events

Statement of the Risk

Over the last several RISC biennial reports, this profile has evolved from extreme natural events to extreme events and ultimately to the current form—Resilience to Extreme Events. This rebranding is more precise and actionable for reasons described in this section. Therefore, the *2025 Risk Report* focuses on resilience to extreme events rather than specifically focusing on extreme natural events.

BPS resilience to extreme events is an area of increasing focus. Reliability and resilience are related but distinct concepts:[13] BPS reliability involves performance consistency under various reasonably expected known or historical operating conditions (keeping the lights on). Resilience, on the other hand, involves the ability of the BPS to absorb and recover quickly from significant abnormal conditions or extreme events (by moderating, if not preventing the impact, and restoring power quickly). NERC Reliability Standards incorporate both concepts with resilience called out as part of the emergency operations (EOP) family of standards. For a more detailed evaluation of NERC Reliability Standards and their contribution to resilience, see pages 8–9 of the 2018 RISC Report on Resilience.

Past NERC assessments indicated that extreme natural events (e.g., extreme temperatures, storms) caused most major BPS impacts. Extreme natural events are continuing and can impact BPS resilience in several ways, including the following:

- Increased intensity, duration, or frequency of events historically typical to a given geographic area
- Instances of historically atypical events, either to a given geographic area (e.g., wildfire) and/or new circumstances (e.g., too much or too little wind, cloud cover or smoke impacting wind or solar generation, respectively)
- Longer-term trends (e.g., higher average temperatures impacting facility ratings)
- Impacts on supply chain and workforce due to geographically larger events

Extreme natural events, such as Hurricane Helene, underscore that extreme natural events pose challenges due to factors including location, intensity, duration, and frequency. Unpredictable weather impacts (e.g., cloud cover impacting solar) challenge operations and can complicate outage management (e.g., greater generation uncertainty challenges scheduling). In addition, manmade challenges, such as physical and cyber-attacks, are becoming more frequent and could pose significant impacts—either as an event initiator or especially if applied coincident with a severe natural event. Furthermore, many new technologies have a larger digital composition, representing an increased cyber attack surface.

[13] Reference NATF/EPRI Resilience definition and NERC Resilience Framework.

Growing societal reliance on electricity and grid transformation makes the resilience context more complex. North America has become increasingly reliant on electricity, exacerbating the impact of any large-scale events. Newer technologies are yet unproven to operate in extreme conditions, warranting added integrated analysis as IBRs and DERs (including behind-the-meter generation) become more prevalent. The transforming grid additionally creates potential deficits in essential characteristics including inertia, frequency and voltage control, reactive control, and blackstart capability. Furthermore, reliance on natural gas generation is challenging due to the just-in-time and uncertain nature of that fuel supply. Planning studies confined to a single sector or region may be inadequate to assess interdependent or cross-boundary events.

Grid operators often add margin to installed equipment during routine replacement and attempt to increase redundancy and diversity during design. However, industry lacks a comprehensive and systematic approach to incentivize resilience investments, and the costs required to significantly “buy down” risk by hardening against high-impact but low-probability events are difficult to justify. Furthermore, the pace of industry changes further strains the timely implementation of such resilience investments. Regulators across North America in places like Texas and Florida as well as FERC are considering this issue.

Taken together, these factors emphasize the need for industry’s ability to recover rapidly from a range of impacts (e.g., an all-hazards approach) by robust mutual assistance, partnering (e.g., with first responders and government officials), strategies to assure availability of key spare parts, blackstart capability, and conducting routine drills. System planning and design need to provide for more flexibility and optionality.

Descriptors of the Risk

- **Extreme natural events, potentially exacerbated by changing climate and weather patterns, continue to present a significant risk.** This includes challenges to grid operators’ ability to cope with traditional but severe events, atypical events (e.g., eastern wildfires, prolonged cold/hot snaps), and high-impact but low-frequency events (e.g., pandemics). See 1a.–c. below.
- **There are challenges caused by human actions.** For example, physical and cyber-attacks may occur alongside natural events, potentially increasing the impact on resilience. See 2 below.
- **Grid transformation effects overlay to make the resilience context more difficult.** The factors include resource adequacy issues, evolving loads (size, pace, characteristics), reliance on other sectors (gas, communications), and supply chain security and deliverability. See 3 below.
- **Industry cannot assess and improve system resilience on pace with the rising threats.** Inadequate long-range planning tools, permitting delays, supply chain shortages, and financial recovery for resilience investments all contribute.
- **Resilience impacts cannot be completely avoided**; industry should focus on these events due to higher sensitivity to environmental conditions and complications to mitigation and prompt recovery. For instance, recent Texas cold weather events showed positive results from generator winterization with limited outages and faster restoration.

Increasingly, non-weather-related extreme events and cross-sector dependence have been recognized as posing added (and potentially layered) challenges to BPS resilience. For example, the COVID-19 pandemic altered all aspects of BPS management, increasing the probability of a severe impact while making recovery even more complex (e.g., through staffing shortages, added challenges managing personnel in a remote mode, and supply chain impacts). Additionally, physical attacks have produced tangible impacts to the BPS. Furthermore, reliance on natural gas generation is challenging due to the just-in-time nature of the fuel supply and the natural gas industries’ uneven approach to winterization. And, while battery storage capacities are increasing, batteries do not provide the same level of resilience that multi-day or multi-week onsite fuel storage provide.

Historical planning and operations techniques cannot assure desired current and future performance as indicated by recent events and associated outages. For example, the BPS has increasing amounts of new technologies and resources that have not fully experienced extreme weather phenomena and may be more sensitive to extreme events in some cases. Furthermore, the new technologies have a significant digital component and represent an increased cyber attack surface and risk for cyber failures. Industry awareness of these changes and prospective performance deficits is being raised by NERC issuances (e.g., Level 3 Extreme Winter Weather Alert and Standards changes, such as EOP-11 and 12 updates). As further experience is gained with the evolving fleet of active lessons learned, the Reliability Standards program will be needed to ensure that the risks are appropriately managed.

While new technology performance does not signal that these technologies and resources are incapable of operating in extreme conditions, it does underscore the need for added integrated system analysis to address them when IBRs, DERs, and behind-the-meter generation become more prevalent. This evolving resource availability during extreme conditions, such as lack of wind during extreme temperatures or lack of solar during winter conditions, must be considered. The precise risk of these having widespread impacts cannot yet be proven because the full penetration of these resources is yet to be realized; however, from a planning and preparation perspective, this cannot be ignored. Other risks described in this report can be “driven” by extreme events: grid transformation, cyber threats, and critical infrastructure interdependencies all have underlying issues that can be exacerbated with the advent of extreme events.

Lastly, there is no comprehensive and systematic approach to incentivize resilience investments. Grid operators routinely add margin to installed equipment during routine replacement and work to increase redundancy and diversity. However, the costs needed to “buy down” risk by hardening against high-impact but low-probability events are difficult to justify and require discussions between regulators and industry participants. Furthermore, the pace of industry changes further strains the ability to identify timely resilience investments. This places a premium on the ability to promptly recover rapidly from a range of impacts (e.g., an all-hazards approach) by robust mutual assistance, partnering with first responders and other critical entities, ensuring that sufficient blackstart capability and energy supplies are within reach when needed, and conducting routine drills.

1a. Historically Typical Natural Events

Various North American regions routinely incur severe natural events typical to that area, such as hurricanes and extreme cold weather. While the risk of these events in those regions is high, the relative impact on the BPS has been low to date. Examples of typical natural events include the following:

- **Hurricanes** can cause widespread destruction to BPS equipment, degradation of communication capabilities, loss of load, and damage to generation resources. Recovery and restoration efforts can be delayed due to the size of the storm as well as damage to interdependent infrastructure.
- **Tornadoes/Derechos** can cause localized destruction to BPS equipment, local degradation of communication capabilities, loss of load, and damage to generation resources. Damage to interconnected infrastructure can hinder recovery efforts, which can be hampered due to local damage to interdependent infrastructure. Further, high wind speeds can lead to wind generation feathering reducing resources available just when they may be needed.
- **Extreme Heat and Drought** can cause higher-than-anticipated demand, overloading and failure of BPS equipment, and degradation of resource availability. Limited water can impact hydroelectric generation and reduce cooling water capacity. Drought can also be a precursor to wildfire risk as described in the next bullet. Extreme heat usually results in low wind speeds, which reduce the wind generation output.
- **Wildfires** can be a direct threat to BPS equipment. Industry can take preemptive actions, such as de-energizing equipment, where wildfire risk is significant. Communication programs and applications, such as new sensing equipment and microgrid deployment, can address some risks. However, such action must be balanced against the added system risk from the associated reconfiguration. Furthermore, wildfires can

reduce output from variable energy resources (e.g., solar) due to smoke, requiring operators to find alternative sources to make up for the loss of energy from these resources.

- **Flooding** can occur in any area and in any season of the year. The impacts from flooding include mechanical damage to BPS equipment, degradation of clearances, fuel infrastructure, personnel access, and communications capabilities.
- **Extreme Cold Weather (Polar Vortices)** can cause higher-than-anticipated demand, overloading and stress failure of BPS equipment, increased reliance on interdependent critical infrastructures, and degradation of energy availability via resource mechanical failure of units or fuel supply interruption. Examples include natural gas wellhead, processing plant, and compressor station freeze-offs.[14]
- **Ice Storms** can be a direct threat to BPS equipment. The impacts from these storms combined with high winds include infrastructure damage as well as limited personnel access and communication capabilities. Examples include the Eastern Canada Ice Storm of 2023.

1b. Atypical Natural Events – by Location, Frequency, or Intensity

Resilience must consider severe natural events that are historically atypical to a given area. This could include the above examples but with added intensity or frequency, gradual longer-term effects, or events atypical to a geographic area, such as the following:

- **Extreme events,** such as Hurricane Helene, which caused extensive flooding in western North Carolina. This storm was large, but the combination with torrential rain for several days prior caused unprecedented flooding.
- **Increased average temperature,** such as those experienced in 2021 when temperatures rose to 120F, challenge facility ratings assumptions.[15]
- **Significant low wind conditions** that impact large amounts of wind generation over a large area or (e.g., Dunkelflaute) can result in the loss of tens of gigawatts of capacity all at the same time. Recent experiences, such as that on June 7, 2023, in the Midwestern United States may signal the need for deeper analysis of these events when they happen and what resources are required to address them.

1c. High-Impact, Low-Frequency Natural Events

Other types of severe natural events, though less likely, could have a higher impact given the potentially broader geographic footprint. See the following examples:

- **Earthquakes** are possible in many areas of the United States and Canada. Depending on the scope and magnitude of the event, BPS facilities and interdependent critical infrastructure may suffer mechanical damage (e.g., communications, fuel, transportation). Earthquake recovery could be long and require further assessment and coordination among utilities and the ERO Enterprise.
- **Geomagnetic Disturbances** can induce harmonic currents in BPS circuits and equipment. In addition, the impacts of these disturbances induce direct currents that may overheat some older transformers, result in relay misoperations, and increase reactive demand and potentially damage reactive resources. Geomagnetic disturbance events can also affect communications capabilities, fuel delivery, and GPS systems.
- **Pandemics** like COVID-19 can greatly alter the way the BPS is operated. Effective telecommuting and cloud-based data exchanges enabled the grid to continue reliable operation and resulted in no major disruptions for power deliveries. However, this altered paradigm underscored the necessity of maintaining proper controls and protocols for security around both systems and human capital.

[14] Cold Weather Project 2021-07: https://www.nerc.com/pa/Stand/Pages/Balloting.aspx

[15] In June 2021, a new maximum temperature of 120F was set in Washington State.

2. There are challenges caused by human action.

Manmade events could have a higher impact given the potentially broader geographic footprint and/or the potential for initiation in conjunction with a natural event. See the following examples:

- **Coordinated cyber and/or physical attacks on the BPS or generation fuel sources,** especially in conjunction with another event (e.g., hurricane, severe cold), could be especially impactful and are continuing to evolve**.** As recently witnessed, even unsophisticated ballistic attacks can result in load loss. Cyber threats are increasing in frequency and sophistication and are benefiting from an increased attack surface as the grid becomes more digitized. Recent important security events include the Colonial pipeline cyber attack and Moore County, North Carolina substation attacks.
- **Supply chain security challenges** at the component and subcomponent levels introduce another dimension to the security challenge along with a growing deliverability concern that could impede restoration activities. Furthermore, while the recent acceleration of AI provides prospective benefits to engineering and operating the BPS, it also likely adds another cyber security dimension for use by bad actors.
- **National security risks,** such as civil unrest, riots, and labor action/strikes, could create potential issues around the physical security of the BPS as well as the safety of critical personnel necessary to conduct the actions needed to maintain the reliable operation of the BPS.

3. Grid transformation effects complicate the resilience context

Several factors combine to pose added challenges for BPS resilience: concurrent significant increases in electrical demand (see Energy Policy); dramatic changes to BPS operating characteristics (see Grid Transformation); the growing prevalence and sophistication of security threats (see Security); de facto reliance on natural gas generation (see Critical Interdependencies); and lagging construction of well-placed, highly resilient transmission. Insufficient integration of these considerations and harmonization of associated actions exacerbate the risk in the following situations:

- **Electrical demand** is projected to rise by 30% by 2050 [16]due to electrification goals and growing data-centric loads like cloud services and AI.
- **Operating characteristics** are changing across North America, including changes in peak demand timing (e.g., intra-day, winter to summer, summer to winter, peaking overnight with electric vehicle charging) and increased sensitivity to small temperature changes due to penetration of electric heat pumps with resistive heating.

4. Industry cannot keep pace resilience threats

- **Traditional coal- and oil-fired generation** is being retired faster than new natural gas and renewable generation can come on-line. This is resulting in added de facto reliance on existing natural gas-fired generation. This increases generation uncertainty given the just-in-time nature of that fuel supply and observed shortcomings in natural gas reliability experienced during recent cold weather events.
- **Construction of well-placed, highly resilient transmission** is not keeping pace with other changes. Transmission siting and permitting is historically arduous, and this combined with jurisdictional issues may result in insufficient timely construction of resilient-design, cross-regional transmission.
- **Supply chain deliverability** at the component and subcomponent level introduces a growing concern that could impede restoration activities.

[16] EIA - Annual Energy Outlook (2025)

5. **Resilience events cannot fully be prevented; industry must add focus to moderating impacts and timely restoration**

- **GridEx is a productive exercise,** but better follow-through is needed to address lessons learned. Further, utilities do not consistently employ more localized drills to improve operator interface with first responders and state and local governments.
- **Positive examples** can be taken from Texas cold weather events based on generator winterization. Outages did occur but were more limited in scope, and restoration was timelier.

Recommendations for Mitigating the Risk

Extreme events and their potential BPS impacts should be rigorously assessed and prioritized to best maintain reliability and improve resiliency. Based on prediction uncertainties, it is important for industry personnel to remain vigilant and prepare for high-risk circumstances by learning from prior events, anticipating impacts, and practicing recovery efforts. Long-range and seasonal reliability assessments should consider how more prolonged and widespread events may stress the system.

Sufficient capacity and energy are needed to prepare for, operate, or when necessary, restore the BPS. The ERO and industry have mitigated some risks by efforts including a cold weather standard for generators,[17] developing a joint NERC/WECC guide on effective management of wildfire,[18] and forming the Energy Reliability Assessment Task Force and issuing the associated Level 3 NERC alert.[19] Furthermore, certain regions may become more dependent on neighbors if generator forced outages are greater than anticipated. These dependencies should be identified.

The RISC encourages undertaking the following actions to ensure the most impact and likelihood of mitigating the risk from extreme events:

- **Conduct assessments:** The ERO Enterprise and industry should conduct event analysis reports on extreme event impacts' geographical areas, including capturing lessons learned, creating simulation models, and establishing protocols and procedures for system pre-positioning and recovery that integrate the following:
  - Critical infrastructure interdependencies (e.g., natural gas for generator fuel, telecommunications, and water)
  - Analytic data and insights regarding resilience under extreme events
  - Implement and sustain actions to address the root causes of major events, such as the FERC/NERC joint inquiries on cold weather outages in ERCOT, MISO, and SPP, and weather impacts related to Winter Storm Elliott. Augment those efforts by developing scenarios that model the effects of the changing resource mix over time and the performance of those resources during extreme events.
    - Based on those assessments and analysis, the ERO Enterprise should develop detailed potential mitigation plans and provide a roadmap for their implementation. The roadmap should include specific protocols and procedures for system restoration and system resiliency.
- **Develop better tools to measure BPS resiliency and incentivize impactful resilience investment:** The Department of Energy (DOE) is performing analyses to evaluate static, dynamic, and real-time scenarios that affect BPS reliability and resilience, Measures should consider key grid characteristics that are evolving, including system inertia; voltage, frequency, and reactive control; and blackstart capability. NERC and industry should collaborate with the DOE on these efforts to ensure that robust tools are available to evaluate potential threats to generation, transmission, and fuel supplies. And, while affordability is a key consideration for industry stakeholders (utilities, customers, and others), inadequate preparation for or recovery from

[17] Cold Weather standard for generators
[18] NERC/WECC guide on effective management of wildfire
[19] Level 3 NERC Alert

resilience events have a significant economic and human toll. The industry lacks a rubric to enable systematic investment on (and financial recovery for) the most impactful resilience enhancements.

- **Accelerate planning and construction of strategic, resilient transmission:** The ERO Enterprise should collaborate with the DOE, FERC, state regulators, provincial authorities, and others to enable timely and sufficient construction of resilient transmission. For instance, prioritize transmission installation with the explicit objective of reducing resilience risk and ensuring "hardening" for anticipated risks (e.g., use of metal/concrete structures in areas of anticipated wildfire risk). It should be ensured that the increased risk of physical attacks on added circuit miles is more than compensated for given risk-reduction benefits associated with added redundancy, diversity, and minimization of very high-risk assets.[20]
- **Leverage Industry forums to share lessons learned on "atypical" events and innovations, such as improved situational awareness and event prediction:** Forums coordinate information sharing on best practices around resilience efforts related to design considerations, supply chain deliverability issues, identification, and response to major storm events. Sharing experiences and best practices is critical, especially regarding recent innovations and lessons learned from atypical events. Industry has demonstrated significant improvements in coping with familiar event types. Florida utilities have significantly improved resilience and restoration from hurricanes through substantial investments in system hardening and restoration activities, even with more intense storms. However, recent resilience events often feature an impact that is atypical to a given area or utility, thereby complicating response. For instance, western utilities are familiar with wildfire. Sharing innovations and lessons learned from those entities would be beneficial to others that have not yet but likely will need to cope with wildfire. Additionally, there has been significant advancement regarding weather prediction and condition monitoring for hazards like wildfire. Efficient sharing of that key information is of significant benefit. In conjunction, NERC should continue to raise industry awareness of key vulnerabilities via various issuances (e.g., Level 3 Extreme Winter Weather Alert and Standards changes, such as EOP-11 and 12 updates).
- **Conduct drills and emergency response:** BPS operators should have formal emergency management programs that include periodic drills and exercises to prepare operators to respond to potentially larger and atypical events. These drills should feature appropriate coordination with applicable state and local resources as well as cross-sector partners. Drills should emphasize actions in response to loss of communications capability and practicing from blackstart conditions.
- **Enhance cross-regional and sector coordination:** States and any other applicable governmental authorities should meet collectively to discuss and understand impacts to ensure that they are a part of the resource adequacy and resilience discussion. This regional coordination will ensure the acknowledgement of roles in understanding the impacts, resilience investments, and implementing mitigating activities, such as formal mutual aid agreements. Similarly, the ERO should actively engage with other sectors, including natural gas and telecom.
- **Encourage closer collaboration between energy subsectors and communications:** The ability to communicate, especially during an emergency, is critical. The industry has seen the impact of communications loss exacerbate scenarios in several recent GridEx exercises. Resilient communications should be pursued in earnest.
- **Raise understanding of potential geomagnetic disturbance (GMD) and electro-magnetic pulse (EMP) events on the BPS:** The ERO Enterprise should monitor industry implementation of applicable actions to help reduce GMD and EMP impact to the BPS.

[20] Debt Ceiling Legislation: Interregional Transfer Capability Determination Study

Recommendation	Timeframe	Interdependence	Risk Addressed
ERO conduct assessments to clarify BPS performance to a range of initiating events and with various levels of grid renewable penetration	1–2 years	Electric, gas, water, and communications	1, 3
ERO work with industry partners to develop resilience metrics to prioritize and incentivize impactful resilience investment	1–2 years	Policy section	4
ERO work with industry and various state and federal jurisdictions to accelerate planning and construction of strategic, resilient transmission	1–5 years	Policy section	4, 5
Industry forums share lessons learned on “atypical” events and innovations, such as improved situational awareness and event prediction	1–2 years	Broad. Applicable to all report sections; comms and gas sectors	All. 1–5
Utilities and key partners conduct drills and emergency response	2–5 years	All sectors, gas and comms primary	4, 5
ERO facilitate enhanced cross-regional and sector coordination	1–3 years	All sectors	2, 3
ERO encourage closer collaboration between energy subsectors and communications	1–3 years	Communications	3
Monitor new developments and share understanding of potential GMD and EMP events on BPS	3–5 years	Security	3

Risk Profile #3: Critical Infrastructure Interdependencies

Key Reliability Risks for the Critical Infrastructure Interdependencies (CII)

The interdependence of the BPS and natural gas, communications, and other critical infrastructure cannot be underestimated. The urgency to mitigate this risk is a national, state, and local issue receiving widespread attention, as can be seen in the significant work being done between BPS stakeholders and the interdependent sectors. These efforts are highlighted later in this section.

<u>In Order of Importance</u>

- **Natural Gas – Extreme Events and Long-Term Supply** The natural gas pipeline infrastructure (natural gas being the primary source of fuel to the dispatchable generation fleet in the next five years) must expand to meet the growing need of these new dispatchable generation units. The interdependence of natural gas infrastructure with the BPS and the lack of comparable natural gas industry reliability standards exacerbates this risk. Also of concern is inadequate natural gas capacity and storage to support the electrical need coupled with the need for more diversity of dispatchable energy resources and ERSs. Another interdependency to consider is the natural gas infrastructure reliance on electricity to operate.
- **Communications**: The operation of the BPS is increasingly reliant on telecommunication networks for real-time monitoring, remote control, emergency response, and system restoration.
- **Other Critical Infrastructure (Water, Wastewater, Transportation, AI):** During extreme or critical events, the BPS incurs additional stress and competes for the use of other supporting critical infrastructure facilities. The forecasted growth of the BPS requires that these facilities also match the growth for a reliable, secure, and resilient power system.

Statement of the Risk

Disruptions to or compromises of other critical infrastructures may affect or disrupt reliable BPS operations. Likewise, BPS disruptions can impact these other critical infrastructures as well.

Significant and evolving critical infrastructure sector interdependencies are not fully understood, resulting in an incomplete understanding of the impacts of BPS disruptions on other infrastructure sectors or subsectors. Key interdependencies of the communication and natural gas critical infrastructure sectors present an elevated risk level to the BPS. Widespread and extended outages of electric and natural gas compressors can result in natural gas delivery issues across the system, impacting not only home heating but also the generation of electricity. Widespread and extended outages of communication systems have the potential to hamper situational awareness and real-time operation of the BPS. The purpose and modality of the BPS data transmitted by critical communication infrastructure may not be well understood by service providers.

The risk level posed to the BPS by water, wastewater, financial, manufacturing, and transportation is secondary in nature. Based on forecasted demand growth, these interdependencies will become more critical as all infrastructure will be strained to meet future electric power demand requirements.

Furthermore, as interdependencies continue to increase between all critical infrastructure due to the transformation of the grid, impacts on one can have a rippling effect on others. An emerging interdependency is developing between the BPS and AI with this technological advance driving the addition of large loads along with the current and future adoption of AI in the planning, operating, and optimizing of the BPS.

Loss of electric service can significantly impact all of the sectors/subsectors that are dependent on reliable, resilient, and secure energy.

Descriptors of the Risk

Natural gas interdependence with the BPS is one of the key risk areas and has two components: extreme events and long-term pipeline build to meet the load growth expectations.

Extreme events (e.g., freezing temperatures, earthquakes, tornadoes, heavy precipitation, wildfires) can have significant impact on the natural gas supply to the generation and to the supply of power to the wellheads, processing plants, pumps, and compressors that are critical to natural gas flow. Recognizing the interdependence between natural gas supply and the BPS would make the continuity of natural gas and power supply a priority for the reliability and resilience of the BPS.

The projected load growth of the BPS over the next 5–10 years makes the addition of generation that can be dispatched or scheduled very important to ensure reliability and resilience. The current projected pace of natural gas pipeline development does not align with the need to supply natural-gas-fired generation impacting resource adequacy. The natural gas pipeline infrastructure (natural gas being the primary source of fuel to the dispatchable generation fleet in the next five years) must expand to meet the growing need of these new dispatchable generation units. Gas pipeline construction takes significant time, money, and regulatory approvals, so it needs to be aligned with the power industry to ensure optimal location and capacity of the pipeline infrastructure.

The operation of the BPS is increasingly reliant on telecommunication networks for real-time monitoring, remote control, emergency response, and system restoration. As the BPS grows in complexity through IBRs, DERs, and large loads, the criticality of the interdependency risk of these on system control and communication systems increases. Disruptions, degradation, or compromise of communication networks can directly impact BPS reliability and resilience. Furthermore, these networks represent a potential attack vector for malicious actors seeking to exploit vulnerabilities in operational technology and industrial control systems (ICS). Ensuring the security, reliability, and resilience of communication infrastructure is paramount to maintaining the stability of the BPS.

BPS reliability is impacted by and impacts other sectors beyond natural gas and communications. For water interdependencies, this intersection is experienced during wildfires when pumps need to be on-line to provide firefighters with water at the same time firefighters can be calling on lines to be de-energized for the safety of their firefighting efforts. That dependency is also seen with sewer systems not being set up to be without power for extended periods, and potable water systems can be tainted if water plants are shut down due to the loss of electricity. Water also serves as a source of power production through hydro-electric facilities—with power production typically the lowest priority use of the river water (navigation, flood control, recreation, and Endangered Species Act operations being other demands on the water). This presents known and understood challenges to hydro-generation. Additional challenges are presented by the dependence on water for cooling at thermal and nuclear generation plants, which is being exacerbated by changing weather patterns, including droughts.

Recommendations to Mitigate the Risks

The table below lists the recommendations and draws from information in the *2023 ERO Reliability Risk Priorities Report*, the expertise of RISC members, and industry comments and feedback and aligns with efforts that are underway or being stood up. Those efforts include the following:

- *March 2025 NERC Reliability Insights: The Interconnected Gas and Electricity Systems*[21]
- National Association of Regulatory Utility Commissioners (NARUC) Gas-Electric Alignment for Reliability (GEAR)[22]
- NERC MRC Input to the Board on Prioritizing Gas-Electric Interdependency Risk and Mitigation Efforts[23]
- FERC + NARUC Current Issues Collaborative[24]
- EPRI Supplemental Project: Nationwide Resilient Communications System (NRCS)[25]

[21] March 2025 NERC Reliability Insights: The Interconnected Gas and Electricity Systems
[22] Gas-Electric Alignment for Reliability (GEAR)
[23] Prioritizing Gas-Electric Interdependency Risk and Mitigation Efforts
[24] FERC + NARUC Current Issues Collaborative
[25] Nationwide Resilient Communications System (NRCS)

Recommendation	Timeframe	Critical Interdependence Infrastructure	Risk Addressed
NERC and industry partners should continue to increase emphasis on cross-sector coordination in industry drills (e.g., NERC GridEx, Public Safety Canada's Cy-Phy Exercise, DOE drills, utility exercises (e.g., Southern California Edison Resilient Grid Exercise)). Scenario specific. Expand GridEx to include additional participants from all critical infrastructure sectors, Develop GridEx scenarios that emphasize interruptions in different critical infrastructure sectors. Critical flaw analysis should be performed, and mitigation should be implemented.	Near Term	Grid Transformation, Resilience to Extreme Events, Security	CII
Market structures and regulatory constructs should be reformed to better assure operational performance and fuel certainty by incentivizing and rewarding actions that promote reliability (e.g., firming fuel supply and transportation, as well as winterization investments). Formalized coordination and collaboration, including the development of standards that encompass both systems, will help assure the reliable operation of both systems.	Mid-Term	Policy	CII
Reform changes should be coordinated by regulatory and permitting organizations for power and natural gas. This will help to shorten the time required for projects to be developed, permitted, and constructed.	Long Term	Policy	CII
NERC and industry should strengthen and deepen coordination prior to seasonal extreme natural events, such as hurricanes, tornadoes, and wildfires. They should also coordinate and prepare for specific events as weather forecasts come into the near term, including positioning fuel, personnel, and incident response team communications across all impacted sectors (e.g., fire departments, natural gas, water system)	Near Term	Resilience to Extreme Events	CII
As the interdependence is strong between the electric and natural gas sub-sectors, these sectors should jointly create weatherization standards. In areas where weatherization standards already exist, benchmarking of performance versus those standards should be performed.	Mid Term	Policy	CII

Recommendation	Timeframe	Critical Interdependence Infrastructure	Risk Addressed
NERC and Reliability Coordinators should conduct new special assessments that address natural gas availability and pipeline common mode failures. These assessments should be implemented at the independent system operator (ISO), state, and local levels.	Near Term	Policy, Resilience to Extreme Events	CII
NERC should conduct a study to determine the percent of available generation with on-site or firm fuel capacity in each Regional Entity. In addition, there should be backup power to compressors and pumps for natural gas supply.	Mid-Term	Resilience to Extreme Events	CII
Improve Communication Protocols: Information-sharing practices between market operators and fuel providers should continue to be strengthened to further align generation capacity with fuel delivery timelines.	Near Term	Policy, Grid Transformation, Resilience to Extreme Events, Security	CII
Further coordinate with cloud storage and communication service providers. This will aid in identifying the purpose of the utility data/communications being transmitted or managed. Security, integrity, and availability of this data is of critical importance.	Mid-Term	Grid Transformation. Security	CII
EPRI and the DOE should continue their work on communication alternatives. New technologies should be explored that could assist in providing unique and hardened back-up telecommunication methods for the most critical data.	Long Term	Grid Transformation	CII

Risk Profile #4: Security

Statement of the Risk

The BPS is a vast, interconnected network that serves almost 400 million consumers across North America, and its security hinges on measures facilitated by the ERO Enterprise. BPS infrastructure continues to grow rapidly with new facilities, services, and technology integrations. This rapid expansion is increasing the cyber attack surface and raising the potential of grid-impacting coordinated attacks.

These transformative changes now include the convergence of information and operational technology, reliance on cloud-based technology, the emergence of AI technology, and potential workforce knowledge gaps. Additionally, dispersed management systems, such as those used by DER aggregators, Internet-of-Things devices, and outage management systems, and the increased automation/integration of operational technology networks are increasing the cyber attack surface while the use of cloud-based hosting or services introduces the risk of code and/or data breach vulnerabilities using third-party software and/or hardware.

Equipment used to monitor, protect, and control the BPS as well as externally connected support systems (e.g., Operations Management System (OMS), voice communications) could be directly exploited. Additionally, interdependent critical infrastructure sectors and subsectors (e.g., communications, water and natural gas used for electric power generation) can be exploited or infiltrated in a manner that impacts BPS reliability.

These vulnerabilities are exacerbated by insider threats, poor cyber hygiene, equipment technical feasibility limitations, and supply-chain considerations. Sources of potential exploitation include increasingly sophisticated attacks by nation-state, terrorist, and criminal organizations.

Cyber and physical security are interdependent aspects, as exploitation of either physical or cyber security vulnerabilities could be used to compromise the other dimension. Resultant impacts could cause asset damage or functionality loss or limit the situational awareness needed to reliably and resiliently operate or promptly restore the BPS. All these factors lead to many challenges for operational security, which is an essential element of a highly reliable and resilient BPS.

Descriptors of the Risk

The descriptors below are divided logically into two categories. Items one through four represent the most serious current risks to the BPS. They are of equal weight in terms of likelihood, impact, and risk exposure. Items five through seven represent emerging risks due to technological changes and workforce developments.

- **Enhanced Threat Environment for Critical Infrastructure**

Advanced persistent threat (APT) actors, which include nation-states and state-sponsored entities, have shown increasing interest and capability in attacking critical infrastructure. Additionally, adversaries have shown an increased focus on ICS and operational technology as vectors for attacking critical infrastructure. Existing threats from transnational groups, organized criminals, and hacktivists also contribute to the overall risk environment. The tactics, tools, and techniques used by these groups are also continuing to evolve and use newer technologies to facilitate cyber compromises.

- **Grid Transformation Security**
  Previously the grid had tens of thousands of devices under control, most of which were generation facilities. Grid frequency, energy balance, and stability were maintained by keeping those generation resources in tight synchrony with demand every few seconds. With increased penetration of generation, storage, and loads based on power electronics, the grid of the future will rely on millions of devices on both the transmission system and distribution systems to maintain reliability. Many of these devices will generally be smaller in size, more numerous, and geographically dispersed and include generation resources, energy storage facilities, and end-use loads, all of which may be asynchronous to the grid. Many of these devices on distribution systems will be controlled by common technologies, protocols, and network connections. The presence of such commonalities expands the attack surface and increases the scale of potential impact of successful cyber compromise or cyber failures. Further, many distribution system resources will likely be operated by a common aggregator likely not subject to critical infrastructure protection (CIP) standards, which creates another risk vector.

- **Physical Security**
  There are several risk factors related to physical security. The E-ISAC notes that most security-related outages are caused by physical security events, including ballistic damage. Some of the largest risks are co-dependent with cyber security (e.g., computer controls for physical access) and the prospective impact of replacing long lead-time equipment (e.g., large power transformers) damaged during an attack. Additionally, there is an ongoing evolution of the physical security risk posed by drones and limitations on response capabilities with existing laws and regulations.

  The increasing dependence of the BPS on vulnerable public telecommunications infrastructure also presents challenges for security professionals, and recent online chatter regarding coordinated attacks is also concerning.

  The Electricity Information Sharing and Analysis Center (E-ISAC) recently highlighted that the frequency of physical security incidents causing operational impacts (customer or generation outages) to the grid remains consistent, averaging less than 3% per year since 2020. Vandalism, theft (primarily copper), ballistic damage, and intrusion (including tampering) were the most frequently reported incident types resulting in operational impacts in the last two years. The most common vandalism threat reported was cut wires, 36% of which targeted fiber-optic cabling—a concerning finding consistent with other critical infrastructure sectors. Impacts from cut wires ranged from customer outages to generation unavailability across a variety of electric assets, including third-party infrastructure. The E-ISAC assesses that 37% of grid-impacting incidents in 2024 were likely sabotage—matched by 69% of online threats assessed by E-ISAC aspiring to sabotage the grid.[26]

- **Supply Chain Security**
  The software and hardware that comprise grid systems, supplied by third parties, have vulnerabilities that need to be mitigated. Managing these vulnerabilities is a complex endeavor that goes beyond security patching and requires utilities to have mature vulnerability and risk management programs. Robust vendor relationship management beyond product acquisition is critical and includes active security assessments, vulnerability disclosure, patching sources, and secure-by-design products, among other features. Contractual security relationships need to be recognized and developed into ongoing collaboration and custodial partnerships. In addition, entities need to plan for circumstances where single-sourced products can be eliminated. These facets are critical to improving national security and the security of the grid.

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26 https://www.nerc.com/gov/bot/bottsc/Agendas%20Highlights%20and%20Minutes/TSC%20Open%20Meeting%20Agenda%20Package%20-%20May%207%202025.pdf

- **Cyber Security Workforce**
  An inability to develop and maintain a cyber security workforce for the electric industry is a critical risk for the ability to identify, assess, and mitigate cyber security risks as well as respond to and recover from cybersecurity events. The current industry workforce is aging, and industry-specific operational technology knowledge will be lost unless these challenges can be addressed. In addition, this challenge requires coupling IT security and technology skillsets with operational technology security and technology knowledge. The competition for talent is exacerbated by the rise in AI and the explosion of growth in data centers.

- **Cloud Security**
  Cloud technologies, including the various delivery models (e.g., Software-as-a-Service, Infrastructure-as-a-Service), present both opportunities and risks in the electric space. Opportunities include scalability, efficiency, geographical redundancy, and cost benefits, while risks include dependency concerns, non-deterministic communications environments, and increased target value to adversary groups as more owners and operators use similar environments. Simultaneously, vendor-provided services and products needed by industry are migrating solely to cloud environments. Additionally, at the intersection of cloud and DERs, it should be evaluated how multiple sites that fall below NERC regulatory thresholds could aggregate risk of critical infrastructure workloads running via the cloud on systems not under a common control center.

- **Artificial Intelligence and Machine Learning Security**
  The advent of generative AI, agentic AI, and improved machine learning is changing the cyber security landscape. As these new AI solutions become more capable and widespread, cyber threat actors will continue to use these tools to mount ever more sophisticated attacks. We have already seen phishing attempts become more difficult to identify as non-native English speakers exploit large language models (LLM) to write grammatically correct phishing attempts. Deepfakes are being used in sophisticated social engineering attacks for financial gain. With this pace of innovation in AI use cases and capabilities, cyber threat actors are leveraging AI to identify vulnerabilities and develop zero-day exploits at an unprecedented rate. In addition, once a vulnerability has been disclosed, use of these AI capabilities may significantly reduce the time window between disclosure and weaponization.

  Additionally, the incorporation of AI into operational systems poses several risks:

  - Overreliance on AI outputs as actionable information in the operation and planning areas
  - The use of AI to develop malware, enhance phishing campaigns, and develop exploitation discovery increasing success rate of compromises
  - Targeting of new technology through maliciously poisoned machine learning training inputs to operating technology may destabilize grid operations

Recommendations for Mitigating the Risk

To continue the efforts toward mitigating the effects of the security risks, the RISC encourages the following actions in order of evaluated criticality to have the most impact and likelihood of mitigating the risk.

Recommendation	Timeframe	Interdependence	Risk Addressed
Through collaboration with industry stakeholder groups, such as the RSTC, NERC should continue developing best practices for grid transformation technologies (e.g., IBRs, DERs) focusing on principles like secure by design, adaptive security, and defense-in-depth across information and operational technology environments.	Near Term	Grid Transformation	Grid Transformation Security

Recommendation	Timeframe	Interdependence	Risk Addressed
NERC should establish a formal working group to address reliability dependencies between telecommunications and electric infrastructure.	Medium Term		Physical Security
Given the time and complexity associated with developing new standards, and the speed with which industries and tools are moving to the cloud, NERC should expedite the development of a security guideline for cloud technologies. This guidance would clarify and give examples of permitted uses of these technologies under existing reliability standards.	Near Term	Grid Transformation, Critical Infrastructure	Cloud Security
The E-ISAC should continue to raise awareness of tactics, techniques, and procedures used by cyber attackers (e.g., email phishing, credential theft).	Near Term		Enhanced Threat Environment
Industry should continue to focus on early detection and response to cyber attacks and adopt controls that can be executed to protect critical systems.	Near Term		Enhanced Threat Environment
The E-ISAC should continue to execute its long-term strategy to improve cyber and physical security information sharing, protection and risk analysis and increase engagement within the electric sector as well as with other ISACs.	Long Term		Enhanced Threat Environment
NERC has been conducting a biennial industry exercise that helps industry both prepare and react to potential BPS security threats. This exercise, known as GridEx, is a distributed-play grid exercise that enables participants to engage remotely and simulates a cyber and physical attack on the North American electric grid and other critical infrastructure. NERC should continue to expand the scope of GridEx to include and collaborate with cross-sector industries, such as natural gas, telecom, and water as well as state, local, and tribal authorities. Future exercises should increase the focus on detection strategies while continuing to improve the ability to respond and expedite recovery. The exercise should promote better follow-through by industry to address lessons learned through the activity.	Ongoing		Enhanced Threat Environment
The design basis for cyber failures should be explored by NERC to determine what designs are more cyber-robust than others and how to de-risk system	Medium Term	Grid Transformation, Critical Infrastructure	Grid Transformation Security

Recommendation	Timeframe	Interdependence	Risk Addressed
components and potential impacts of cyber vulnerabilities.			
NERC, while collaborating with industry, should continue to evaluate the need for additional assessments of the risks from attack scenarios (e.g., vulnerabilities related to drone activity, attacks on midstream or interstate natural gas pipelines or other critical infrastructure). NERC's lessons learned exercises have been helpful and require additional focus through seminars that educate the industry on best practices in system security planning.	Near Term		Physical Security
Through industry stakeholder groups, such as the RSTC, research risks related to reliance/dependencies between vulnerable public telecommunications infrastructure and the BPS.	Near Term		Physical Security
Efforts are underway to improve software supply chain security through an "energy star" type of label for secure third-party products, or, as it is called in Executive Order 14144, the United States Cyber Trust Mark. The designation can apply to products to show secure development but can also apply to trusted vendors in recognition of their security capabilities and ongoing client services to ensure diligent management of threats and vulnerabilities. NERC should collaborate with industry to support such efforts in the electric sector. Supply chain risk management and the threats from components and sub-components developed by potential foreign adversaries should continue to be addressed by the E-ISAC, other federal partners, and industry to continue diligently working to mitigate threats.	Long Term	Grid Transformation, Critical Infrastructure, Energy Policy	Supply Chain Security
NERC should continue to encourage conversations around enhancing supply chain risk management (SCRM) through interactions with industry and government stakeholders.	Near Term	Grid Transformation, Critical Infrastructure, Energy Policy	Supply Chain Security
NERC should continue to support cloud enablement for the industry through development of standards modifications and promote discussion and outreach. Furthermore, NERC should evaluate whether cloud security programs like FedRAMP can be leveraged.	Medium Term	Grid Transformation, Critical Infrastructure	Cloud Security

Recommendation	Timeframe	Interdependence	Risk Addressed
NERC and industry should continue to facilitate the development of planning approaches, models, and simulation methods that may reduce the number of critical facilities and thus mitigate the impact relative to the exposure to attack.	Near Term	Grid Transformation, Critical Infrastructure	Grid Transformation Security
NERC should study the implications of cyber design failures and their impact on grid reliability. This will enable improvement opportunities and strengthen the system against cyber security threats.	Medium Term	Grid Transformation, Critical Infrastructure	Grid Transformation Security
Industry stakeholders should continue to share physical secure bulk data logs with the E-ISAC on a voluntary basis.	Near Term		Physical Security
Due to the competition for talent, industry should evaluate the salaries and benefits of cyber security personnel to be competitive in this new market. In addition, allowing for workforce flexibility (work/life balance, maternity/paternity leave, remote work when possible) would be incentives to the new generation of hires. Maintaining the stability of staff would also be a positive benefit to employee retention. Expansion of the talent pool and areas of recruitment is critical to securing top talent. Extensive recruitment to high schools, trade schools, and former military/federal employees is key to developing and maintaining a leading cyber security workforce.	Medium Term		Cyber Security Workforce
Offering part-time employment/contract work to subject matter experts (SME) of the organization's staff to train the new hires allows for continuity of the knowledge base.	Near Term		Cyber Security Workforce
Through industry stakeholder groups, such as the RSTC, NERC should collaborate and develop industry guidance on best practices to mitigate potential risks posed by the use of AI technologies. This guidance should be tailored to the electric industry.	Medium Term	Grid Transformation, Critical Infrastructure, Energy Policy	AI and Machine Learning

Risk Profile #5: Energy Policy

Energy Policy Volatility as a Reliability Risk Factor

“Energy policy” refers to the legislation, regulations, and market frameworks established by the legislative bodies; federal, state, and provincial regulatory agencies; and regional transmission organizations (RTO), ISOs, and other entities that influence infrastructure development, grid operations and energy sufficiency. For this report, particular attention is directed at policies that address decarbonization, decentralization, and the planning and operation of the BPS.

Without question, energy policy can drive changes in the planning and operation of the BPS. Unfortunately, not all of these policies are specifically aligned with the physical needs of maintaining a reliable grid, and may result in reliability impacts. Though the broader energy policy objective is desirable, these policies may result in reliability impacts. Accordingly, policy can affect BPS reliability and resilience and could present risks to its reliable operation. Greater alignment and consistency across state and provincial regulatory agencies, RTOs, ISOs, and regional transmission planners and operators could help address differing requirements and improve coordination, potentially enhancing reliability across the BPS.

In recent years, policy volatility has emerged as a risk driver, as rapidly changing policy perspectives can further complicate and exacerbate risks to reliability, impacting capital investment strategies and creating market uncertainty. The business certainty necessary to make investments in new generation capacity depends in part on the durability of applicable policy. Implementing major policy shifts without factoring in timeline impacts can undermine reliability, given the long-term planning and investment decisions necessary to operate a system as complex as the BPS. Sudden or large changes in policy, or short-term orders, can negatively impact the business climate with implications for energy sufficiency, the pace of interconnection of new resources, and ability to meet new demand, recently exhibited by the desire to integrate large loads. Because ensuring reliability during and after policy-driven transitions is critical, durability should be a key consideration in setting energy policy.

The implementation of policy decisions can significantly affect the reliability and resilience of the BPS, and sudden reversals in policy can compound risks. Implementation plans should be carefully considered to avoid unintended consequences affecting resource planning. For example, federal and state policy over the last decade and more have facilitated the expansion of IBRs, such as solar, wind, and battery storage. IBRs now represent as much as 90% of new generation capacity added annually and the vast majority of resources in interconnection queues with policy support and technology advances successfully making these resources economically attractive sources of energy. However, the resulting interconnection queue delays have added to project development uncertainties and encouraged more project submissions, complicating the integration studies required to ascertain grid reliability and the system planning studies needed to balance load growth projections with generation.

Implementation of policies affecting the BPS is accelerating, and extreme weather events, and physical and cyber security challenges, reliability implications are emerging with changes in the resource mix. Demonstrated risks, such as energy sufficiency, natural gas and electric interdependence, and operational reliability concerns, are becoming increasingly critical. These critical interdependent risks may intensify if energy policies shift abruptly. For instance, as projections for load growth rapidly increase, uncertainty or abrupt changes in energy policy, particularly at the federal level, may pose a risk for interconnection of new resources and consequently for energy sufficiency.

Policy Misalignment

The electric grid faces growing reliability and modernization challenges due in part to misalignment among the policy objectives, implementation plans, and timelines of various policymakers, compounded by permitting constraints and significant load growth from emerging industries, such as data centers. Such inconsistencies and conflicts can lead to delays and inefficiencies that can constrain industry's ability to respond to grid challenges.

Key risks include the following:

- **Grid Reliability:** Misaligned policies and implementation timelines, combined with permitting delays, hinder the ability to address increasing load growth and aging infrastructure upgrades. NERC and various Regional Entities and RTOs have highlighted the risk of resource additions failing to keep up with generator retirements and load growth as well as the need for ERSs to be maintained. Increased electrification coupled with rapid expansion of data centers—high-density energy consumers concentrated in specific regions—further stresses local grids, particularly where transmission and generation capacity are already constrained.
- **Infrastructure Bottlenecks:** Lengthy development and construction processes, driven in part by the wide range of jurisdictions and agencies with grid oversight, and local opposition delay both critical new transmission projects and upgrades and the addition of new generation resources needed to meet rising demand. This is particularly problematic in areas experiencing significant load growth from data centers, EV adoption, and electrification of other sectors, potentially leading to localized outages or grid instability.
- **Energy Resource Integration:** Integrating diverse power sources—such as natural gas, nuclear, and IBRs—requires enhanced transmission and storage infrastructure to meet growing demand and ready the system to address extreme weather events. Permitting delays and misaligned policies slow the deployment of these critical upgrades, further straining the system as demand from data centers, other industries and electrification continues to rise.

The interplay of federal-state policy misalignment, permitting challenges, and rising load growth underscores the need for coordinated strategies to modernize the grid, streamline permitting processes, and ensure that sufficient energy with sufficient levels of grid resilience is available in the face of growing energy demands. Emerging potential risks are increasingly concerning. Due to the interdependence of critical infrastructures (e.g., electricity, natural gas, water, transportation, and communications), potential reliability risks can be magnified when cross-industry subsectors and agencies act independently to create or implement policy. The development of Reliability Standards and processes recognizes and respects the jurisdictional authorities setting and implementing policy decisions. It will take strong collaboration and partnerships across a multitude of boundaries—state, federal, provincial, and private—to mitigate the emerging risks that we face today and ensure that the reliability of the grid is a prioritized tenet of critical infrastructure.

Technical Considerations Associated with Policy Development

Policymakers need to be sufficiently familiar with the technical challenges of operating the grid. Energy policy decisions that do not align with the operational capabilities of the electric grid will likely increase reliability risk. In the current environment, three active policy areas warrant particular attention: energy sufficiency, the emergence of load loads, and the interdependence of the natural gas and electric markets. Each area is discussed briefly below.

Energy Sufficiency

Energy sufficiency is when the resources available are able to produce enough energy to meet energy demand at any given time. With demand increasing, there is a premium on interconnecting and deploying new resources rapidly to assure energy sufficiency. Policy implementation timelines, and proposed modifications to policy, should actively consider the ability to ensure energy sufficiency.

Existing resource adequacy requirements and underlying studies have traditionally been based on a paradigm that focused on peak capacity requirements and assumed that energy sufficiency would result; traditional resource adequacy planning is capacity-focused. As the resource mix continues to rapidly change from one that was limited by rated capacity to one where fuel/energy is constrained and weather dependent (e.g. by available wind, sunlight, or gas supply), new approaches are needed to assess and ensure energy sufficiency for all hours throughout the year. Limited-duration resources also change the way energy sufficiency is measured. It is becoming increasingly important to consider available energy and not just forecasted power. Broadly impactful, long-term, and widespread weather events are highlighting energy sufficiency issues from the changing static/dynamic characteristics of the resource mix and technology lag.

Large Loads

Data centers represent the primary large loads being integrated into the electric grid, playing a crucial role in supporting national security, economic stability, and societal functions. The reliable and timely connection of these loads is a national priority. These facilities, which can demand hundreds of megawatts at a single site and thousands of megawatts in a geographically small area, operate continuously, have minimal tolerance for power quality issues, and can be interconnected rapidly, often outpacing the development of accompanying transmission and generation. Failure to address the integration of large loads from a policy perspective could exacerbate the reliability considerations associated with energy sufficiency and resource adequacy challenges. These loads should continue to be evaluated through the NERC Large Loads Task Force and other industry forums to identify risks and mitigation strategies. Constructive engagement is underway within industry to understand performance characteristics and operational capabilities of these loads. Encouraging this collaboration to continue can help inform the development of effective policy frameworks that promote the continued growth of these large loads in an efficient and reliable manner, given the critical economic and national security interests impacted by this sector.

In addition, by regulating the development and operation of infrastructure essential for reliable power, permitting is a crucial factor that affects data center reliability and resource adequacy. This is a particular concern in this area given the speed of data center development and construction.

Natural Gas and Electric Interdependency

Natural gas and electricity markets each developed independently and, because they were not designed to work together, at times are not fully coordinated in terms of operations, scheduling, or timing. Natural gas access for power generators is further challenged by other priority uses, including home heating and industrial and manufacturing processes. While progress has been made on these fronts through formal collaboration at venues like the North American Energy Standards Board (NAESB), the National Association of Regulatory Utility Commissioners (NARUC), and NERC and informal collaboration among participants of both markets, the need for additional progress has been well documented in connection with extreme weather events, such as winter storms Uri and Elliott.

Issues that further coordination efforts could address include power market challenges to natural gas pricing, advance purchasing, advance scheduling, dispatch, and cost recovery—all of which are needed to reduce generator uncertainty, including natural gas supply availability during times of system stress or very high demand. In addition, future coordination efforts should continue to focus on increased alignment of natural gas and electric scheduling and the challenges that electric generators face in accessing natural gas during critical periods, such as severe winter weather events, particularly over weekends and holidays.

Policies promoting cleaner energy sources have increased reliance on natural gas for electricity generation, while electrification of natural gas infrastructure, such as pipelines and compressors, deepens their interconnection. For instance, cold weather impacts both energy subsectors, reducing their ability to deliver energy. Decarbonization policies and renewable energy mandates further complicate this relationship, as natural gas often serves as a flexible backup for variable energy renewables. Furthermore, ERSs that are vital for the reliable operation of the BPS also become highly uncertain. Infrastructure permitting, market regulations, and emergency preparedness policies directly impact the availability and cost of natural gas for power generation and the reliability of electricity for natural gas operations.

Perhaps the most vexing dilemma is identifying potential avenues to increase and support investment in gas infrastructure. NERC and its Regional Entities have highlighted this issue across a number of reports and reliability assessments. In addition, gas infrastructure could be further challenged by the projected addition of new natural gas generation to meet new load growth. Additionally, large loads that liquify natural gas for sale and transport, whose infrastructure resides within a local electric utility footprint, represent a critical area for coordination and collaboration, particularly during extreme weather events.

The electric reliability and resilience impacts caused by ongoing challenges between the natural gas and electricity markets should be sufficiently accounted for in risk assessment, planning, and operations. Additionally, remaining challenges can continue to benefit from increased cross-industry and cross-jurisdictional communication, coordination, and collaboration. Public policy that fails to consider the challenges of gas-electric coordination will place additional pressure on grid reliability. Because the electric and natural gas industries arguably have a higher degree of critical infrastructure interdependencies, increased policy collaboration and coordination should occur between these sectors.

Recommendations for Mitigating the Risk

- Policymakers should adopt a three-pronged principles-based approach to decision making:
    - In addressing the foregoing complexities, policymakers should prioritize the principles of reliability (including resilience, and security), affordability, and environmental sustainability in their decision-making processes. Policymakers need to understand the importance of establishing a coherent strategy that aligns with these guiding principles that supports the electric industry’s ability to engage in the long-term planning and investment crucial for developing the generation capacity needed to meet the expected demand. These principles could guide the industry’s evolution, ensuring a balanced approach as stakeholders seek to meet growing demand in the face of supply chain constraints, escalating costs, and a variety of environmental imperatives.
    - At the heart of this strategy lies the principle of reliability, which encapsulates the electric system's ability to deliver consistent service to all customers. Given the scale of current and pending reliability challenges, as policymakers consider the principle of reliability in this three-pronged approach, they must recognize the need for concerted progress on several fronts (e.g., transmission infrastructure, energy supply resource development, maturity of control systems, better planning and analytics tools, comprehensive contingency plans). This requires having all options available and points to the importance of adopting a durable “all of the above” approach that considers energy sufficiency and the full spectrum of resource options and services required to keep the BPS reliable. This includes ERSs provided by generators, such as inertia, ramping capability, voltage support, and blackstart capability. These services are foundational to maintaining grid reliability. The foremost priority for policymakers must be securing the resources necessary to ensure energy sufficiency and provide ERSs. By aligning this priority with an “all of the above” approach that recognizes development timelines and the unique capabilities of each generation technology, policymakers can effectively uphold the principle of reliability while also balancing affordability and environmental stewardship.

- Leveraging the benefits of such a consistent, principles-based policy approach requires two conditions precedent:
    - **Technical education for policymakers**
    First, given the complex nature of BPS planning and operations, education for policymakers and regulators to increase awareness of both the technical challenges of operating the grid and the reliability implications of policy decisions is critical.
    - **Increased coordination and collaboration**
    Second, increased coordination and collaboration between federal, provincial, and state policymakers, regulators, owners, and operators of the BPS as well as with the critical interdependent sectors/subsectors are needed. Communication, coordination, and collaboration should be early, consistent, and clear to bridge increasingly complex jurisdictional lines.

Recommendation	Timeframe	Interdependence	Risk Addressed
Policymakers should adopt a three-pronged principles-based approach to decision-making.	1–2 years	Broad – applicable to all risk profiles	Policy volatility; Policy misalignment
Policymakers should adopt a durable “all of the above” approach that considers energy sufficiency and the full spectrum of resource options and services required to keep the BPS reliable.	1–2 years	Grid Transformation, Resilience to Extreme Events, and Critical Infrastructure Dependencies	Policy volatility; Policy misalignment
Prioritize technical education for policy makers	1–2 years	Broad – applicable to all risk profiles	Technical deficiencies in policy development
Prioritize increased coordination and collaboration	1–2 years	Broad – applicable to all risk profiles	Policy misalignment