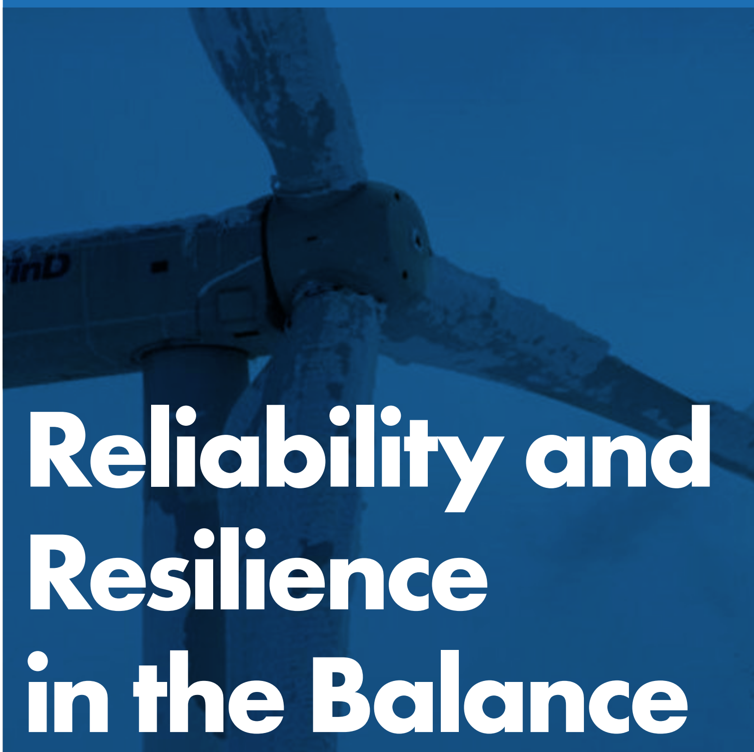
Prepared by

ASCE

TEXAS SECTION



Reliability and Resilience in the Balance

Building sustainable infrastructure for a reliable future.

A vision beyond Winter Storms Uri and Viola.

Network Report & Executive Summary

January 2022 | Full Report coming soon

Report prepared by:

American Society of Civil Engineers (ASCE)
Texas Section

Beyond Storms Infrastructure Network Resilience Task Committee

As a public service, the American Society of Civil Engineers (ASCE) regularly prepares assessment reports of critical infrastructure serving essential needs on both a state and national level. Most recently—early February 2021, the Texas Section of ASCE (ASCE Texas Section) released its current Infrastructure Report Card (IRC).

As well, when a catastrophic event takes place and infrastructure fails, ASCE deploys skilled engineers from its membership to assess and determine what happened, why it happened, and more importantly, to develop recommendations for future change, as appropriate, to avert such an event. As such, **ASCE Texas Section convened a task committee as Texans experienced Winter Storms Uri and Viola.**

Learn more at www.TexASCE.org/beyond-storms.

ASCE Texas Section is one of the largest and most active sections of the American Society of Civil Engineers, the oldest national civil engineering society in the United States. Established in 1913, the Texas Section represents nearly 10,000 members throughout Texas. The Section is headquartered in Austin and comprises 15 Branches around the state and Student Chapters at all the state's leading universities. ***Texas civil engineers are leaders in their communities, building a better quality of life across the street and around the world.***

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Executive Summary

The twin impacts of Winter Storms Uri and Viola on Texas and its energy system were catastrophic. The consequences for Texans were tragic. These impacts included at least 210 Texans who lost their life during the storm and substantial and lingering economic impact to the entire region that is estimated to exceed $200 - $300 billion[1] in addition to disputes and securitizations. The economic impact of Uri and Viola were greater than the impact from either of the two most costly hurricanes[2] in US history, Harvey ($145B) or Katrina ($161B). In comparison, in 2019 Texans spent around $37 billion on retail power during the *entire year*[3]. Regardless of the metric, from public safety to economic impacts Uri and Viola deserve a comprehensive response to prevent recurrence.

The weather system event of February 2021 was severe. It was the first time in history that all 254 Texas counties were placed on winter storm warning. Fortunately, the physically damaging ice storms during Winter Storms Uri and Viola were localized in impact and wind was relatively moderate. Temperatures were not. Some experts have indicated that Winter Storms Uri and Viola were a 1 in 100 or 1 in 130-year system event. The severity of a winter storm's impact to infrastructure has four primary dimensions to consider: 1) The number of days when temperature is below 32°F for an entire 24-hour period (TMax). 2) The number of days on both sides of TMax when minimum temperatures for at least1 hour during the 24-hour period was below 32°F (TMin). 3) Precipitation – especially freezing precipitation that can lead to physical damage and 4) Wind damage impacts from wind chill accelerating cooling or physical damage – especially when combined with freezing precipitation.

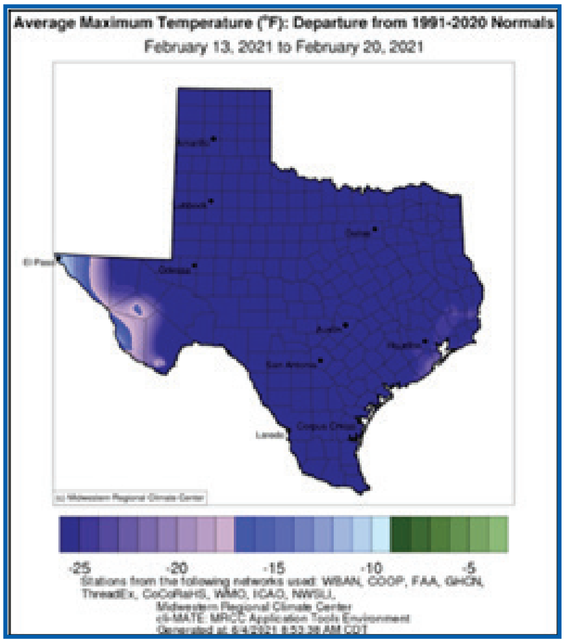


Figure 1: TITLE

On a macro, Texas-wide basis, Uri and Viola presented extreme in TMax and TMin conditions relative to historic major winter storms in Texas. In comparison, the number of TMax days experienced during Winter Storms Uri and Viola was last experienced in a January 1940 winter storm and the storm of 2011 had < 50% of the number of TMax days of Uri and Viola. On the remaining two storm dimensions Uri and Viola was more moderate with respect to wind extremes and relatively localized on freezing rain precipitation. *[Figure 3]*

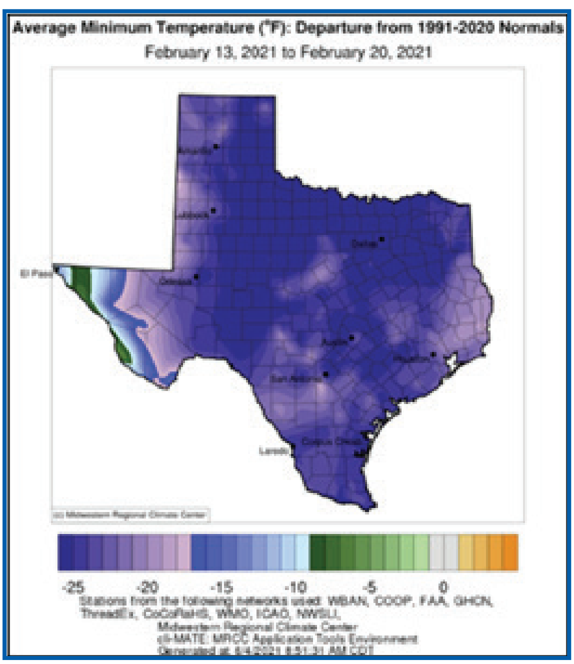


Figure 2: TITLE

Uri and Viola had direct impact on infrastructure across Texas, from agriculture to roads and homes that generated substantial economic and personal harm. The weather also complicated the response. Transportation corridors became impassable from accumulated freezing precipitation, hindering the response capabilities of people and equipment to respond to essential infrastructure problems, which often compounded the problem. There is no effective tool to be able to allocate specific responsibility of what impacts were directly from the weather itself, what was directly impacted by the failure of the electric system and what were indirect impacts. However, ASCE Texas Section believes that the failure of the electricity grid was directly and indirectly a material contributor to the economic harm and human tragedy experienced during and after Winter Storms Uri and Viola.

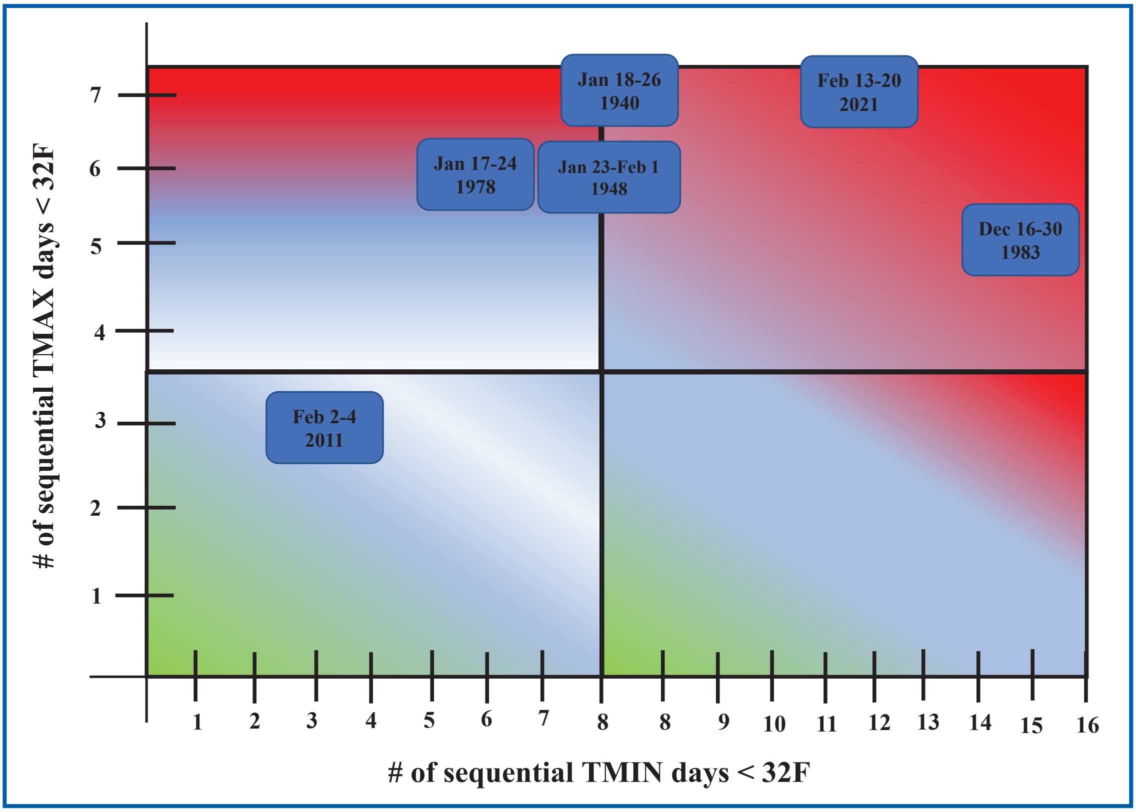


Figure 3: TITLE

The problem that ASCE Texas Section discovered is that too much focus on the storm distracts attention from the more critical issue. **Major reliability failures were exposed by Uri and Viola, but these failures extend well beyond winter storm events.** Texas has a substantial and growing electric system reliability and interdependence problem. The balance of this summary network report focuses on these more critical issues.

A reliable and resilient electric system in an increasingly electrified economy is critical to the safety and economic health of our fellow Texans. ASCE Texas Section's urgency is driven by the conclusion that the failures that caused overwhelming human and economic suffering during February ***will*** increase in frequency and duration due to legacy market design shortcomings, growing infrastructure interdependence, economic and population growth drivers, and aging equipment even if the frequency and severity of weather events remains unchanged.

Texas has long been a leader in energy and innovation. The Texas electric grid has been in a constant state of evolution to accommodate new technologies, grid expansions and satisfy growing demand since its formation. During the current transition, substantial federal and state incentives supporting new intermittent wind and solar resources have led to the dramatic growth of renewable energy resources in Texas. Recent and growing additions of utility scale energy storage confirm another stage of transition. ASCE Texas Section recognizes that the grid will continue to evolve and that the grid of the future will not look like today's grid. ASCE Texas Section does not subscribe to the view that reliability deterioration is an inevitable part of the "cost of transition" in the energy sector. Due to the extreme costs of reliability failure, it is ***reckless to believe*** that the energy market transition should somehow be used as justification or an excuse for reliability declines and extended load shedding events. For energy transition to work effectively and be accepted, it must occur without any sacrifice of reliability and resilience.

The energy industry is one of the most complex and capital-intensive industries in the world. Like almost all critical infrastructure, it requires large, routine capital expenditures to support expansion, maintenance, and operations to meet demand. Policies, regulations, and market actions that distort, constrain, or negatively impact the flow of capital to needed investment starves reliability through deferred expansions, delayed maintenance, and reduced reliability investment. The reliability of critical infrastructure, from transportation and energy to water, wastewater, and telecoms, is heavily impacted positively or negatively by ***revenue sufficiency*** - the sufficiency and predictability of ongoing investments supporting maintenance and reliability upgrades.

There is a legacy of chronic under-investment to maintain critical infrastructure of all types across the US, from roads and bridges to water infrastructure, airports, and telecommunications. Even though it costs more, routine maintenance is frequently deferred into the future to become "someone else's problem". The result is that infrastructure from bridges to wastewater treatment plants slowly deteriorate until far more costly investments become unavoidable. Unfortunately, many of the negative impacts of this under-investment are felt more acutely by those individuals at the margin, who must rely on critical infrastructure with few viable options. Underfunding creates other problems including worsening public safety and compliance issues. This pattern of deferral and avoidance, results in a costly "run to failure" outcome followed by surprise that reliability and resilience was somehow compromised. This pattern of persistent underfunding must change. Some leading cities, like the City of Houston are implementing a pay as you go policy that includes reducing debt and keeping more current on maintenance and upgrades to their critical infrastructure. These cities understand that run to failure is not a strategy. *[Figure 4]*

To understand the root cause of the Winter Storms Uri and Viola a, it was necessary to look beyond the physical infrastructure and to include the impact of regulations that apply to the use of the infrastructure and the markets themselves. The energy infrastructure system works or fails by how well these three legs of the energy market work together. ASCE Texas Section identified two primary related problems: (1) a failure to economically support reliable dispatchable power generation (ensure revenue sufficiency) and (2) the negative impact from sources of intermittent electric power generation. This assessment concludes that revenue insufficiency from ERCOT's energy-only market model, influenced by federal and state subsidization of intermittent resources (mainly solar and wind), fails to adequately pay for reliable dispatchable generation and that these market model deficiencies are the leading contributor to making the ERCOT system less reliable.

This market design and supporting rules and regulations in place rely on the concept that potential periodic scarcity premiums would be sufficient to incentivize long-term reliability investments. There is ample evidence that this model is unfounded. According to Wood Mackenzie[4], "...During the 10 years prior to 2021, ERCOT's Energy-only market did not provide a meaningful signal for natural gas or wind generators to winterize." A dispatchable generator confronting this reality rationally is unlikely to invest in winterization, firm fuel supply, dual fuel flexibility or make other reliability and availability investments. The hope that these investments will still be made despite ***neither*** market revenues nor forward markets support this outcome is unsupportable.

For example, the analysis by NERC/FERC confirmed that a majority (as much as ~75%) of the generators in ERCOT experiencing natural gas outages and/or derates during the storm relied on a mixture less expensive, non-firm interruptible transportation and/or interruptible gas supply to fuel their operations, while those generators with more costly firm supply and transportation received delivered fuel that closely matched their nominations during the storm. Based on the lack of revenue sufficiency from ERCOT's energy only market design, generators appear to have made rational decisions to defer a wide variety of investments, from winterization to firm fuel supply, and other reliability investments.

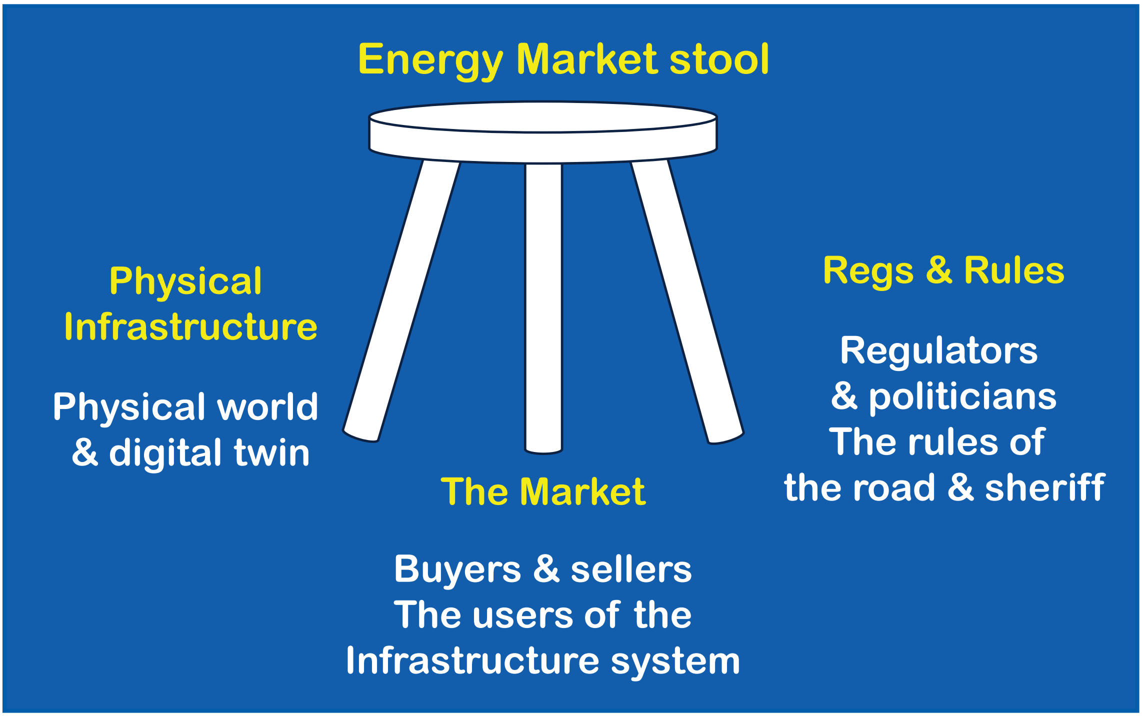
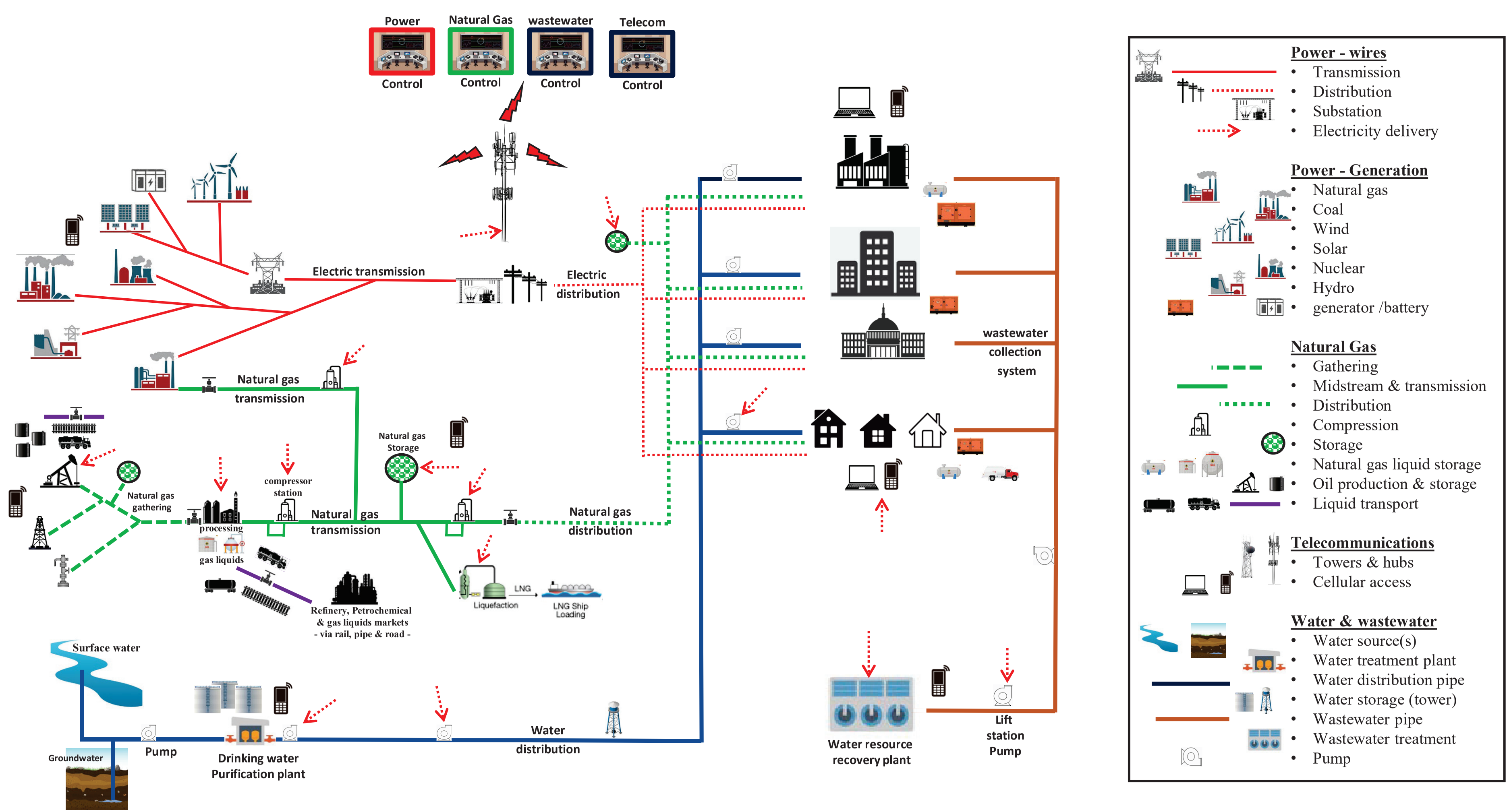


Figure 4: Energy Market Stool

Figure 5: Network Model with Interdependence



The next most consequential contributor to reliability degradation is the relentless creep of interdependence between infrastructure sectors, which contributes to increasing the fragility of each system(s) and sets the stage for cascading failures across sectors. Interdependence occurs when the reliability of one sector is mutually dependent on the reliable performance of another sector. The water industry provides a unilateral, or one way, interdependence example. The loss of electricity led to the loss or interruption of water supply to customers, which led to the issuance of boil water notices to those customers. The industry simultaneously lost real time situational awareness and control of their water networks as SCADA (Supervisory Control And Data Acquisition) controls lost power and/or communications with operational controls and field sensors. The natural gas and electric sectors provide an example of a bilateral reliance and interdependence problem where two infrastructure sectors were mutually dependent on each other. The field level power failures experienced by the gas industry curtailed the fuel supply needed to fuel dispatchable power generators. Like market-based pricing and transition to renewable generation, interdependence between infrastructure sectors is not going away. The impacts of interdependence will continue to deteriorate reliability without action – but proactive steps can be taken. It can be mitigated, fragility improved, and reliability enhanced by implementing a series of actions that are (1) relatively modest in scale, (2) focus on enhancing reliability of ERCOT and (3) mitigate interdependence risk between critical infrastructure sectors.

The two remaining key contributors to reliability degradation work in more subtle ways. These two contributors include rules, policies and regulations that create negative impacts to reliability and a legacy ERCOT philosophy that has prioritized low cost to the detriment of reliability.

What does the potential solution cost?

This is a very complex issue that requires resources far beyond the scope of this report. However, a simplified, approach[5] considered an existing capacity-based power market, that compensates for reliability, for an ***indicative*** answer. PJM is a capacity market Regional Transmission Organization (RTO) that has what they term a Reliability Pricing Model (RPM) operating in the eastern interconnect. PJM is a larger market than ERCOT. This simplified analysis considered the average capacity cost over a 10-year period from 2011 to 2021 in PJM and adjusted this to the equivalent size of ERCOT. Over this ten-year period the amount would have translated to a total cost of $14 billion. This equates to $1.4 billion per year. This adjusted amount equates to < 5% increase in prices in ERCOT (a $37B annual energy market in 2019) and is a relatively modest level of notional investment for improved reliability and resilience. This provides an indicative level the relative reliability and resilience investments expected. The value of reliability is overwhelming. and the actual costs of reliability are likely to be lower when implemented and market forced brought to bear. **ASCE Texas Section's 5 network recommendations** follow, as well, its sector-level review of five prioritized infrastructure sectors including water, telecommunication, electricity, transportation and energy.

1 Invest in Black Start capacity to ensure reliable, fail-safe back-up

Electric transmission systems must be maintained in constant balance between supply and demand. When the transmission system experiences severe overload, usually from an imbalance between demand (load) and supply (generation), protective relays automatically initiate load shedding of interconnection lines to protect critical components of the grid. If the imbalance conditions persist, there is the potential for the entire grid going down with a complete loss of all electricity supply on the grid resulting in what is called black start condition. During Winter Storms Uri and Viola, ERCOT narrowly averted such an event by ~4 ½ minutes on Monday, February 15, 2021. Large areas of the state could have suffered without any power for weeks or even months . The concept of restarting the grid to restore power appears simple, but the reality is far more complex. Many safety and control systems will have been compromised in an emergency shutdown. Each of these must be inspected, isolated, and repaired if necessary. Generators have a great deal of rotating equipment including pumps, safety, and control systems that must be operating when returning the generator to service. In normal operations, the power plant relies on power supplied by the grid to start-up this equipment. Under black start conditions power plants must rely on special "black start generators" to provide this emergency restoration energy source. Black start generators are the ultimate backstop to the system. They must be well maintained, highly reliable and able to operate under a wide range of conditions supplied by dependable fuel supply. If these generators fail to start, operate, or have compromised fuel supply, they cannot support restarting the grid.

In ERCOT, there are 13 primary black start generators (the primary fail-safe to the system) and 15 secondary generators (the equivalent of back-up generators to the back-up generators) for a grand total of 28 generating black start units. According to the Black Start Working Group Presentation dated June 3, 2021: 9 of the 13 primary black start generators experienced an outage during Uri and Viola or had forced outage and tripped offline and 12 of the 15 secondary generators had forced outage events during the Energy Emergency Alert (EEA). This means that a total 21 of 28 (75%) black start generators had operational problems during the winter event. The ***most critical generation*** used to avoid black start conditions from occurring and if everything else fails, ultimately perform as fail-safe generators to restart the grid under black start conditions failed to operate reliably on any industry performance metric scale. Further impacting reliability, 18 of these 28 units rely on natural gas their only single fuel resource.

Black start emergency capability and reliability must never be compromised. Texas must provide consistent, reliable, and adequate funding of sufficient term to satisfy revenue sufficiency for the black start generators including the incremental capital and operating expenses to support the following reliability investments for **all** black start generation:

- **Require dual fuel capability with a minimum dedicated on-site fuel storage of 14 days running at 24/7 with regular best in class testing of this capability.**
- **Require winterization, reliability, and performance investments consistent with top decile, best-in-class performance.**
- **Black start generation that is incapable of dual fuel service or unable to meet minimum top decile reliability and resilience metrics should be immediately replaced, unless it is a hydroelectric resource with sufficient storage or run of the river reliability.**

2 Restructure regulatory flaws negatively impacting dispatchable generation reliability

The ERCOT energy only market structure prioritized low cost over reliability. This has predictably led to chronic underinvestment in reliable generation and is directly responsible for the ongoing erosion of reliability from dispatchable generation. This market design and supporting rules and regulations in place rely on the "hope" that potential periodic scarcity premiums would be sufficient to incentivize long-term reliability investments. However, the continued hope that these investments will still be made when market participants observe that ***neither*** market revenues nor forward markets support these investments and that these markets are the only to be paid for these investments would be more accurately described as a form of reliability gambling. The growing dependence on less reliable, intermittent wind and solar resources increases reliability risk and subjects Texas to a potential tipping point where, absent change, load shedding with its overwhelming social and economic impacts will likely become a routine event. In ERCOT natural gas generators have a mixture of firm and interruptible transportation and supply contracts that vary by generator. Increased levels of cycling due to variability of intermittent resources increase the financial risk of these firm year-round commitments and will likely force some of those generators to relinquish these fixed obligations. The changing nature of demand will also require new natural gas infrastructure to support this evolving operational need. Fundamental changes in the market are needed to appropriately compensate dispatchable generation for reliability, independent of whether it is called upon or not on a given day. Predictable and reliable revenue sufficiency is required to support the long-term capital investment and operating expense to achieve the desired system reliability.

ASCE Texas Section offers a hybrid approach to enhance the current energy-only model with a reliability focused solution:

- **Ensure revenue sufficiency for reliability and dispatchability that include winterization, firm fuel supply, market area storage, reliability investments, dual fuel capability (as needed) and supporting infrastructure (upstream).**

- **Simple-cycle Gas Turbines should be supported through revenue sufficiency to convert to dual fuel capability with liquid storage capacity for secure winter peak availability, fuel and price diversity benefits, and as contributors to prevent a black start condition.**

- **The PUCT, consistent with TX SB3, must establish industry-leading operational and reliability metrics applicable to the generator, including weatherization, with financial consequences applied for failure to generate reliably during extreme weather events.**

- **All generators must meet their bid commitment with incentive and penalty solutions apply to all generators that miss their bid (high or low) within transparent bands of tolerance with cost causation penalties borne by the generator that failed to perform consistent with the tolerance band and top quartile Forced Outage Rates.**

- **Incremental intermittent generation should bear the cost of negative reliability impacts on the system that requires funding reliability payments to dispatchable generation or complementary reliability capability with similar duration tenor.**

3 Mitigate growing interdependency between infrastructure sectors

ASCE Texas Section have identified two related actions that are increasing the interdependency between infrastructure sectors and contributing to reduced system reliability and sector resilience. ASCE Texas Section believe that these issues were material contributing factors in cascading failures across infrastructure sectors. The first is **Explicit Interdependence**, where major reliance by one sector, such as telecommunications reliance on electricity is well known. ASCE Texas Section identified a growing complexity in infrastructure that ASCE Texas Section refers to as **Interdependence Creep**. This occurs where individual decisions about integrating with another sector might not rise to a level of concern but when this one-off integration is repeated hundreds or thousands of times the result creates a systemic issue. The increased reliance on electricity driven solutions by the natural gas industry for full and partial field electrification of production, controls, operations, electric trace heating, compression and storage is increasing the fragility of both sectors. Public policies, regulations and business decisions that increase interdependency must consider and include the quantification of reliability considerations. Interdependence will continue to increase and get worse without action.

The natural gas industry must harden critical natural gas infrastructure to help ensure reliable natural gas service that all consumers rely upon. The Texas RRC should take steps to:

- **Implement new standards for all new upstream and midstream infrastructure to ensure minimum reliability and resilience continuity standards during extreme weather events and work with industry on prioritized investment(s) to upgrade existing infrastructure.**
- **Full and partial field electrification is causing step change increases in interdependence. Mitigate growing interdependence through support of cyber secure microgrids and back-up power solutions at identified critical natural gas infrastructure locations and complemented by transportation and telecommunication strategies for prioritized continuity of service.**
- **Generators must be required to pay for the quality of service that it requires and not rely on subsidization by the natural gas industry.**
- **RRC should lead the effort in working with industry, ERCOT and the PUCT to develop contractual arrangements with the LNG industry provide compensated flexibility to temporarily redirect their natural gas for short term emergency peak system needs.**

Other steps and reliability enhancements:

- **Applicable critical infrastructure sector regulators must support individual infrastructure sectors to implement back-up solutions to their internal operational and control systems to ensure that operators maintain operational control and oversight of their systems. Local Distribution Companies (LDC's) must prove their ability to remotely implement and manage a demand rationing scheme in the event of curtailments.**
- **Outage planning and return to service must be proactively managed and scheduled to ensure that there are no coincident major outages scheduled above certain thresholds.**
- **ERCOT and PUCT should encourage increase utilization of back-up power and robust, cyber-secure microgrids, that reinforce and enhance the reliability of the grid. LDCs should be able to develop, own and operate microgrids outside of the rate base in competition with 3rd parties.**
- **Discourage reliance on paper-based reliability solutions like the Critical Load Filing (CLF) unless LDC's establish a relative ranking of firm loads, complete distribution investments to support the CLF, and ensure the firm load is included in ERCOT seasonal planning efforts to accept and approve the firm load.**

4 Establish a foundation of reliability-focused regulations and incentives

Prioritize reliability focused regulations and incentives and eliminate regulations that include the unintended consequences of creating negative impacts to reliability. Regulations and market designs can negatively impact reliability, or they can enhance systemic reliability on the grid system. There are regulatory structures that burden the grid and reduce reliability during periods of extreme demand. Subsidizing activities that result in negative impacts to reliability must be eliminated. Policies that enhance or contribute to reliability should be encouraged.

ERCOT should ...

- **... work with the PUCT to preclude returning end user demand (individual, microgrid, industrial, etc.) that returns demand during system peaks and emergencies unless approved by ERCOT.**
- **... implement new System policies that prevent utility scale batteries from re-charging (consuming power) during ERCOT load shedding or allow them to be net consumers of power during the EEA events unless required by ERCOT**
- **... increase support and incentivize dispatchable renewable resources from biomass, waste to energy, geothermal, hydroelectric, and long-duration energy storage (> 24-hour).**
- **... ensure a sufficient number of credit providers are accessible on an over the counter (OTC) basis and available 24 hours a day, 7 days a week during severe weather events.**
- **... work with LDCs to identify and plan for interdependence mitigation investments and process changes to improve both systemic reliability and customer level reliability. All essential infrastructure, like water and wastewater, should have minimum interdependence mitigation plans implemented consistent with minimum reliability and resilience standards.**

On a systemic basis we must consider reliability centric approaches to funding and maintaining infrastructure. This new approach to sustainably manage our critical infrastructure is required for critical infrastructure to maintain reliability and resilience and to be economically sustainable. The legacy approach of "run to failure" is far more expensive and it disproportionately impacts the most vulnerable members of our society. There are some lessons that can be taken from what happened in ERCOT about what worked and what failed. These lessons can then be applied to other critical infrastructure, not only in Texas but beyond. There are four lessons for consideration:

- **Reliability and resilience is a societal expectation in critical infrastructure.**
- **Establish revenue sufficiency requirements to adequately operate and maintain critical infrastructure in an economically sustainable manner.**
- **Confirming evidence of revenue sufficiency could be required prior to approval of major capital underwriting of both new and upgraded capital investments.**
- **Periodic public reporting, independently confirmed, of progress towards becoming economically sustainable on critical infrastructure is a transparent metric for measuring the management, stewardship, and economic viability of critical infrastructure.**

The ASCE Infrastructure Report Card has been a foundational tool to help inform stakeholders and policy makers about the physical status of the major sectors of critical infrastructure across the United States. This has been a very effective tool to inform and educate the public and policy makers about essential infrastructure and where critical infrastructure requires major capital investment. Regulators, policy makers and industry leaders also need to develop an understanding of the substantial value created from ensuring that critical infrastructure is also properly supported and managed to ensure that it is economically sustainable operationally and from an ongoing maintenance perspective. A foundation of economically sustainable operations and maintenance will contribute to a more reliable and resilient system of critical infrastructure in the future.

The following table provides a range of policies and issues that impact reliability. *[Table 1]*

Table 1: Range of Policies and Issues that Impact Reliability

Reliability Policy Matrix	Reliability Damaging Policy	Reliability Supporting Policy	Reliability Prioritized Policy
Black Start Generation	Inadequate capacity payment to maintain revenue sufficiency	Reliability investments to achieve top decile KPI performance. Require dual fuel capability and provide revenue sufficiency to support top 10% reliability.	Require dual fuel capability in all black start generators with 14-day 24/7 fuel supply stored on site.
Liquid Fuel Conversion	Low load factor black start generators reliant on a single fuel	Require dual fuel capability for all black start generators with min. 14-day 24/7 fuel supply storage on site with capacity payment for conversion & storage.	All simple cycle combustion turbine required to be dual fuel capable and compensated for storage and conversion in capacity payment. Evaluate dual fuel flexibility for portion of CCGT fleet
Intermittent Generation	Little or no consequences for intermittent reliability impacts	Economic incentives to manage daily production within tolerance of bids applied to ALL generation. Capacity payment to dispatchable generation for confirmed availability regardless of actual dispatch.	Supporting policy + incremental intermittent generation to require contracted dispatchable capacity to offset system for reliability impacts
SCADA and Management Systems	Most critical infrastructure lost its situational awareness due to electric system outages and lack of interdependence mitigation.	Require all incremental system solutions to include parallel management capability in event of telecom and power system failures for all critical & major systems	Require independent system outside of telecom and power system for field systems to ensure continuity of service and situational awareness.
Microgrids	Allowing microgrids to return to ERCOT during EEA	Robust cyber secure microgrids that can't return to ERCOT during EEA events and establish operating standards for microgrids to satisfy for grid connection.	Robust cyber secure microgrid. Access ERCOT during excess supply and supplement ERCOT during EEA events. Allow LDC's to own/operate microgrids
Natural Gas Winterization	RRC of Texas has no winterization requirements on natural gas production.	RRC of TX develop appropriate minimum winterization standard requirement to support industry reliability and resilience for all new production	RRC of TX develop appropriate minimum winterization standard requirement to support industry reliability and resilience for all new and existing production
Seasonal Market Simulation and Simulator Exercises	Focus on summer gaming and limit to ERCOT and governmental participation	Require seasonal market simulation with required participation across all critical sectors prior to start of season. Each market participant required to participate and be certified.	Reliability supporting policy plus development of a market simulator for routine testing and certification of operational participants
Natural Gas Storage	Lack of capacity payments undermines investment market area storage needed to reliably support variable electric demand	Encourage development of market area storage for electric generation through capacity payments that allow commitments by electric generation.	Require risk adjusted percentage of high deliverability market area storage to ensure minimum of 2 days of 100% fuel demand of gas fired CCGT.
Dispatchable Renewable Resources	Discourage participation in market by dispatchable resources due to energy only structure	Encourage dispatchable renewable resources from biomass, waste to energy, geothermal, hydroelectric, and long-duration energy storage (> 24 hour).	Offer premium value in market for dispatchable resources that are dispatchable. Hold to same performance standards for FOR and related metrics.
Critical and Essential Load Management	LDC reliance on paper-based system for CLF w/o supporting system controls installed and inability to implement load shed	CLF deadline and validation complete prior to and integrated with seasonal firm load forecast and acceptance by LDC that it can physically support the load.	Robust SCADA, relay and switching systems to support rolling load shedding. Prioritize critical loads, require back-up generation to serve minimum load level.
Demand Side Management	Allowing curtailable customers to return to service during EEA	Load focused DSM with industrial, commercial and office space (especially CBD areas with low storm occupancy) prioritized for load curtailment.	All customers included in DSM. Discourage heat pumps for residential unless strip heating supplement controllable by LDC DSM program.
Utility Scale Batteries	Allow batteries to recharge during EEA period. Allowing batteries to be net consumers of power during EEA	Prevent battery recharging when operating reserves drop below minimum-security levels. Restrict recharging during EEA except when authorized by ERCOT	Limit incremental short-term battery storage until LT (1 day +) storage (of any technology is available)
Vegetation Management (VM)	Various standards	Ensure proactive vegetation management across all T&D systems	Require proactive risk-informed VM programs coupled with condition-based management cycles to improve reliability
EV Recharging	Allowing recharging during EEA	Encourage off-peak recharging of EV through incentives like TOU rates	Supporting policy + allow grid to call upon EV battery resources during EEA
LNG	LNG is a significant & growing year-round firm gas demand reducing gas system flexibility.	Consider LNG peaking fuel supply stored on site of generator as alternative to liquid fuel conversion of GTs.	Create economic option with LNG terminals for short-term interruption during certain emergency events.

5 Prioritized a reliability and resilience culture and best cost approach

Replace process and model biases and the reliability sacrificing pursuit of short-term cost reductions with a reliability and resilience prioritized culture and best cost approach

The over-reliance and failure of a model driven culture was on display prior to, during and after Winter Storms Uri and Viola. Extended regulator-driven clearing prices set at its limit of $9000/MWh despite a lack of incremental generator response, resulted in higher prices but not more generation. Forecasts, models, and expectations were materially inconsistent with reality. The subsequent response to the storm doubled down on this strategy with a fix the model solution approach to solving reliability shortcomings instead of candid discussions concerning areas that require fundamental re-thinking. This problem is compounded by a distinct lack of clear ownership and accountability for performance that is a common element in the legacy ERCOT leadership internal self-reflection about the events and a focus on their cost vs. reliability of the system.

Reliability and resilience are not performance outcomes that can be inspected or audited into the system. Reliability must be integrated into daily operations like how a business successfully approaches safety. An updated report or model may provide new insight, but seldom does it fix reliability issues. It takes actions. It usually is complemented with physical infrastructure upgrades and processes. It takes dynamic thinking and willingness to question everything. If reliability and resilience is truly integral to ERCOT then training and gaming the system must happen far more frequently and include other industry players and government officials to reflect the reality of infrastructure interdependence.

Recommendations:

- **Conduct disaster simulation exercises that include all impacted critical infrastructure entities (natural gas, water & wastewater, telecommunications, transportation and governmental agencies), are needed to regular test and sharpen skills in response to system emergencies, identify process and risk areas. These should be reinforced *prior to* winter and summer seasonal periods. Seasonal focused gaming and training should be scheduled and completed prior to the beginning of the season. A system disaster simulator that includes interdependent sectors, like what has proven effective in training pilots and nuclear plant operators should be developed for ERCOT and include other interdependent sectors and encourage active training and experience between sectors by sector teams.**
- **ERCOT should be periodically reviewed by an independent agency and benchmarked against leading independent system operators.**
- **ERCOT must be held fully responsible for changing its processes and decision making to prioritize reliability of the system. This responsibility should not be diluted or delegated. The PUCT should be the entity responsible for holding ERCOT accountable for changes, metrics, and Key Performance Indicators.**

End Notes

[1] The Perryman Group (2021), *Preliminary Estimate of Economic Costs of the February 2021 Texas Winter Storm*, February 2021. (low case = $197.2B, High case= $295.8B)
[2] The Perryman Group (2017), *Preliminary Estimate of Economic Costs of Hurricane Harvey*, August 31, 2017 ($145B). and NOAA.gov Office of Coastal Management, *Fast Facts - Hurricane Costs.*
[3] US Department of Energy, Energy Information Administration: https://www.eia.gov/electricity/state/.
[4] Wood McKenzie (Woodmac.com) 2021; *Texas Grid Failure and Implications for the energy transition*; March 4, 2021.
[5] T Popik and R Humphrys (2021). *The 2021 Texas Blackouts: Causes, Consequences, and Cures*. Paper and presentation The Journal of Critical Infrastructure Policy, spring/summer 2021.
[6] Electric Reliability Council of Texas (ERCOT) (2021) *Review of February 2021 Extreme Cold Weather event*, February 25, 2021, Pages 17 & 21.

Affected Infrastructure Sectors

Report Summaries

The following part of this executive summary reports provides a single page summary of each Sector specific infrastructure report and their respective recommendations for:

- Telecommunications and Fiber
- Drinking Water, Wastewater, and Stormwater
- Electricity
- Energy
- Transportation

These reports and assessments were developed to address the more unique infrastructure sector specific issues from these five areas. While there are several consistent themes and similar recommendations, each Sector report is designed to be able to stand on its own.

Telecommunication Infrastructure

Telecommunications and fiber are an inseparable part of every critical infrastructure sector for communications. Most utilities rely on a SCADA system for monitoring, maintenance, and control needed for the safe and reliable operation of their systems. Financial institutions, healthcare, military, and government sectors rely upon proper functionality of the telecommunications sector to be effective, save lives and mange communities. This evolution of interconnectedness with telecommunication systems has not only revolutionized and made systems more efficient, but it has also introduced new threats resulting from natural disasters and deliberate cyber-attacks threatening to disrupt operations and public safety.

The Public Utility Commission of Texas (PUC or PUCT) is a state agency that regulates the state's electric, water, and telecommunication utilities, implements respective legislation, and offers customer assistance in resolving consumer complaints. The PUC's mission is to "protect customers, foster competition, and promote high quality infrastructure."

Winter Storms Uri and Viola impacted the Telecommunications Infrastructure Sector and in turn the critical infrastructure sectors interdependent upon continuous telecommunication service. Widespread and prolonged power outages negatively impacted telecommunications service. The impacted service hindered situational awareness and, in some instances, control of remote operations by utilities and essential service providers. Cell phone service was unavailable in certain areas, leading to the inability to make calls or text. While this created an inconvenience to users, it negatively impacted first responders and operators of essential infrastructure to respond to emergencies, repairs, and service restoration in a safe manner. Radio broadcast stations were also impacted by power outages. This is particularly important for local public updates during power outages which may limit information access to broadcast radio.

ASCE Texas Section recommendations for the Telecommunications Sector:

- **Improved hardening of site telecommunication facilities/infrastructure for weather extremes:** The impacts from Winter Storms Uri and Viola were severe and often exceeded scenario assumptions for telecommunication facilities and infrastructure. This requires greater preparedness for harsh weather conditions in the future. A comprehensive review of specific issues experienced including the identification of risk areas for improved maintenance and modernization efforts.
- **Consider expanded redundancy of select infrastructure:** Develop plans to include redundancy in key quality of life infrastructure sectors (e.g., power and water) to be reviewed and approved by PUCT.
- **Education and outreach to interdependent infrastructure.** Telecommunication drives business and the safe and reliable operation of critical infrastructure relied upon by society and business. Develop renewed and updated risk mitigation plans with operators of critical infrastructure to identify steps and potential redundancy investments that can be taken and deployed that can mitigate the potential loss of situation awareness and control of their systems. Ensure regular testing of public outreach by governmental agencies during emergencies under stressed scenarios.

Water, Wastewater, and Stormwater

The State of Texas had 7,056 water systems serving 29,096,493 people in 2019 and 3,876 wastewater outfalls in the State in 2021. This complex system of water resources (i.e., water, stormwater, and wastewater) relies on other infrastructure sectors, including but not limited to, transportation, energy and communications that materially impact water resources and vice versa.

The cascading events of the unexpectedly prolonged power outages and extreme temperatures experienced during the Winter storms Uri and Viola in February 2021 tested many water utilities. As the temperatures dropped and water demands increased due to customers' utilization of water for dripping their faucets combined with private premise plumbing breaks and water main breaks, many water utilities had to treat and distribute water to meet demands that abnormally reached or exceeded peak summer day levels. Power disruptions impacted potable water delivery to customers and led to shortages of bottled water. Extended power outages caused system communication and pumping disruptions and led to extensive boil water notices impacting nearly 40% of community public water systems across Texas.

Based upon our observations, ASCE Texas Section recommends the following:

- **Improved operational preparation for severe weather events.** Consider increasing the amount of treatment capacity available during the winter months, based on updated demand planning criteria for winter months. Identify and implement improvements at production and pumping facilities that would provide additional flexibility in scheduling required maintenance. Develop Standard Operating Procedures (SOP) for reducing chemical usage in emergency conditions while maintaining water quality and evaluate increasing chemical storage on-site at treatment plants. Water providers must fill treated water storage tanks prior to the forecasted beginning of significant weather events. Ensure vehicles are equipped with snow tires or chains in advance of freezing weather. Consider adding snowplow attachments for heavy equipment. Utilities should implement seasonal SOPs to routinely prepare for winter weather, such as pipe insulation, draining non-critical piping, storing strap-on boot spikes, bedding, and MREs and ensure manual access options to critical facilities with electric security.
- **Mitigate infrastructure interdependence risks.** Evaluate increasing the number of backup generators, including both permanent generators and trailer-mounted portable generators, including natural gas fired generators where reliable natural gas service is available. Ensure fuel additives are available and in use prior to freezing weather. Collaborate with power providers on additional resiliency measures, such as dual power feed and automatic switching capabilities. Consider backup power and/or secured cellular service options to maintain SCADA systems and situational awareness.
- **Educational outreach.** Educate the public on the need for maintaining a disaster supplies kit, including basic items a household may need in the event of an emergency and the potential loss of water. Utilize resources such as ready.gov for information on what a person will need to survive for several days after a disaster. Educate customers on locating and safely operating their premise water shutoff valves.
- **Enhanced planning to reduce risk.** Water utilities should evaluate pipe breaks that have occurred in their distribution systems, including those experienced during Winter Storm Uri. Break data should be analyzed to determine age, pipe materials, and other causes of pipe failures. Utilities should investigate the ability to use ARRA funding to assist with the cast iron pipe replacement projects. Where indicated by the analysis, utilities should develop programs to replace cast iron pipes in the water distribution systems, using prioritized based performance data. Include emergency response to the list of benefits when justifying Automated Metering Infrastructure (AMI) implementation.

Electricity Infrastructure

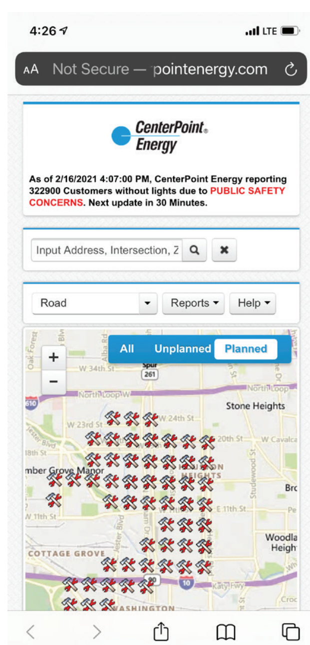
The electricity infrastructure network, or "the grid" as it is commonly referred to, consists of four primary components that must operate in perfect harmony. The infrastructure components of the electrical power grid network are generally considered to be: 1) Generation, 2) Transmission, 3) Distribution, and 4) Substations, including control systems which serve to connect each of the above primary systems components and modify (step up or step down the voltages) for the next step in electricity's journey to the end user. Under deregulation of electric power in Texas, generation of electricity has been decoupled from transmission, distribution, and substations. The overall grid itself is managed by the Electric Reliability Council of Texas (ERCOT), under regulatory oversight of the Texas Public Utility Commission. Generation and retail marketing of electricity are provided by firms not economically regulated in Texas.

The impact of Winter Storms Uri and Viola on Texas and its energy system was catastrophic and are covered in depth elsewhere in this report. This team observed that there were several critical sector specific issues exposed during this winter storm event including:

- Ineffective generation sector market incentives to develop and implement a culture of high reliability and resiliency.
- Failure to heed prior warnings and recommendations for power generation and fuel supply infrastructure winterization was evident.
- Gaps were found in the "load shed" methodologies used by electric distribution utilities, specifically in how "load shed" quantities were allocated and managed.
- Failure to properly identify and coordinate between the natural gas and electric industry to exclude certain critical natural gas infrastructure from having electricity service curtailed.
- A limitation from limited grid interconnectivity between the Eastern, Western, and ERCOT grids greatly limited the potential for load demand sharing to better manage the high load demand resulting from this winter storm event.
- Critical weaknesses in "Black Start" generation readiness were exposed.

Based upon these observations, the ASCE Texas Section makes the following recommendations for the Electric Sector:

- Properly incentivize the market, particularly in the generation component, to develop and implement a high reliability and resiliency prioritized culture that includes a focus on winterization and dependable fuel supply infrastructure.
- Rationalize the current "load shed" methodologies used by the power distribution utilities to ensure effective allocation between distribution utilities and load shed execution.
- Ensure exclusion of critical interdependent natural gas infrastructure from ordered load demand response. Adopt routine market simulation exercises between the electric and natural gas industries to develop awareness of solutions to interdependent operational challenges.
- Evaluate expanding grid interconnectivity between the Eastern, Western, and the ERCOT grid for emergency load demand sharing situations reduced the potential options available to manage the high load demand resulting from this winter storm event.
- Take steps to ensure "Black Start" generation is able to perform with top decile performance and reliable fuel options under a wide range of adverse conditions.



Energy Infrastructure

ASCE Texas Section determined that "**freeze-off**" of natural gas production was a factor in precipitating some aspects of the February major load shedding event. However, other factors highlighted by the Network Executive Summary stated above, including the impact of the extended cold weather generated by Winter Storms Uri and Viola and incipient contractual obligations and market dynamics, played outsized roles in the cascading disruption of the electrical generating capacity for the Texas Electrical Grid.

Had adequate methods of heat tracing and insulating of critical field natural gas production components been employed, the flow of natural gas to gas fired generating facilities would have been sustained at a higher level, perhaps at most 20% or 2.34 BCF, in advance of the severe interruption of electrical power in the early hours of February 15, 2021. That availability of additional natural gas may have served to mitigate the severity of the load shed event, to a degree that at this time can only be estimated by ERCOT and the electrical power generation companies feeding the Texas Grid.

Therefore, the recommendations from ASCE Texas Section for the Energy Sector to mitigate the recurrence of significant interruptions of natural gas fuel supplies to critical power generation operations in the Texas Electrical Grid are as follows:

- Review and apply cold temperature process protection procedures used in field production well sites of areas in the mid-continent of the United States.
- Install heat tracing and/or insulating elements to the areas of field oil and natural gas production process where valves are used to throttle the flow of process fluids and gases.
- Natural gas production operations supplying the Texas Electrical Grid should apply for exemption from having electrical power interrupted during an ERCOT declared EEA and be unable to participate in incentives for electric load curtailment.
- Regulating entities managing the Texas electrical grid and the Texas oil and natural gas industry should implement approaches to ensure that electric generators are acquiring the quality of firm and non-firm supply and transportation services and related services such as market area storage needed for reliable power generation to meet peak winter demand periods. This effort must respect the quality of contracted service and not expect subsidization of electric generators by the natural gas industry to provide services more than the level contracted and paid for, eroding reliability of the natural gas industry and shifting costs to other users of the natural gas system.
- Regulating entities managing the Texas electrical grid and the Texas oil and natural gas industry should develop contractual requirements for temporarily curtailing the supply of natural gas to Liquified Natural Gas export facilities during the time that an ERCOT declared EEA is in force in return for appropriate compensation.
- Texas oil and natural gas field production operations should supply field maintenance crews with articles and equipment that provide the capability to respond safely on an emergency basis to remote well sites in the event of a severe weather service interruption.

Transporation Infrastructure

Texas has nearly 314,000 miles of roads and highways, more than any other state. The transportation sector also includes airports (400), mass transit systems and passenger rail, freight rail (10,400 miles of track) and 21 seaports, including three (3) of the busiest ten (10) ports in the nation, and an intracoastal waterway.

Winter Storms Uri and Viola impacted every aspect of transportation, from closed airports to stranded transport trucks en-route, delayed transit times, and shut down shippers and receivers. Sea ports became increasingly backlogged and many railroad companies, were nonfunctional for periods of time. As a result, truck capacity plummeted which resulted in steep spikes for demand in the market and put pressure on contracted pricing. Disrupted power supplies caused freight that normally would take one day to cross into Laredo to take two (2) to three (3) days. Imports by truck from Mexico were delayed for days which impacted the state and the nation. Treacherous road conditions, from ice and snow, kept many drivers out of Texas, and those drivers in the state remained immobile. These road conditions delayed crews and supplies from reaching critical natural gas, electric, water and telecommunications infrastructure for repairs, maintenance, and restoration of service. It also negatively impacted supply chains limiting food and fuel supplies in certain areas. Extreme weather conditions extending into all reaches of the State were exacerbated by vehicles operated by inexperienced drivers operating for the first time on icy roads and bridges. The treacherous driving conditions resulted in hundreds of car accidents. The most notable of these accidents was the 130-vehicle pile-up on Interstate Highway 35 near downtown Fort Worth, TX that claimed 6 lives.

The ASCE Texas Sector recommendations for the Transportation Sector include:

- **Greater preparedness for weather extremes:** The impacts from winter storms Uri and Viola were severe and often exceeded scenario assumptions included in emergency operations plans. This requires greater preparedness for harsh weather conditions in the future. A comprehensive review of issues and a consideration of lessons learned from other infrastructure sectors, such as ensuring manual access to electronically secured facilities during power outages and ensuring steps have been taken to mitigate interdependence risks from loss of power supply at critical facilities are some of the areas for consideration. This review should include the identification of risk areas for improved maintenance and modernization efforts.
- **Consider updates to Emergency Operations plans:** TxDOT has a well-developed Standard Operations Plan (SOP) for emergency operations in snow and ice. This system includes a four-tiered system of road prioritization for treating primary state highways across the State. Tier II focuses on local and regional roadways of importance in collaboration with local governments. This should be expanded with input from the electric and natural gas industries, the TRC and the PUCT to ensure that access to critical energy infrastructure is included in the prioritization.
- **Education and outreach.** Extreme weather conditions highlighted the need for education of the public about extreme weather warnings, including governmental agency warnings to stay off road during inclement weather to prevent or minimize a need for first emergency responders. Persuade local governments and agencies to adopt TxDOT's approach to conduct emergency exercises to test emergency response plans and ensure reliable local and regional communication during emergency events. The exercises help identify ways to improve the plan's features for safe and reliable performance during a winter weather response.

ASCE Texas Section

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