

The Texas Freeze Out: Electric Power Systems, Markets and the Future

BY MICHELLE MICHOT FOSS, PAT WOOD III, AND BRETT PERLMAN

Backdrop

During February 7-21, 2021 an Arctic oscillation, a “polar vortex”, enabled freezing air to penetrate the U.S. midcontinent into Mexico, forcing temperatures below long-standing records for durations that also set new records.¹

The extent and duration of power outages in Texas garnered national and international attention. In this article, we add observations on what we believe we have learned as of this writing.

Tracking the Event

As early as November 5, 2020, meteorological warnings were issued by the Electric Reliability Council of Texas, ERCOT, which oversees most of the state’s grid, to all market participants warning of the possibility for an extreme cold event during winter 2020-2021. During late fall 2020, weather forecast services began to include discussion of shifting conditions.² On February 3, 2021, ERCOT warned market participants of the coldest weather of the year (Figure 2). These warnings tracked news and alerts from commercial weather outlets. As the timeline progressed, ERCOT issued an Operating Condition Notice, OCN, an advisory, and a watch. During an ERCOT Board meeting on February 9, 2021, ERCOT’s CEO warned

the Board that ERCOT “might have a little bit of winter weather to contend with.”³

A Texas Energy Reliability Council (TERC) meeting was held on February 12. TERC brings together the two regulatory bodies within Texas – the Railroad Commission, RRC, which oversees the states natural gas industry and the Public Utility Commission of Texas, PUCT, which oversees electric power. Through TERC, the RRC and PUCT coordinate with ERCOT and the natural gas industry to manage curtailments. The RRC curtailment plan gives “highest priority for gas availability and delivery on residences, hospital, schools, churches and other human needs customers”.⁴ By emergency order that day, the RRC took steps to update its 1973 curtailment plan to prioritize “deliveries of gas to electric generation facilities which serve human needs customers,” a step it had been first advised to take in 2003.⁵

Communications and interactions across the key agencies and gas and electric industries intensified as weather conditions worsened (Figure 2). These

culminated in an appeal for conservation measures on February 14.

The shock to the energy system unfolded as shown in Figure 3. By noon on February 15, ERCOT had crossed all three levels of emergency operations, invoking an Emergency Energy Alert (EEA) 3 early on February 15 and directing transmission operators to curtail 10,000 MW of firm load.⁶

In the Figure 4 panels, we show electricity generation by source for the month of February 2021 and since 2014. These compare with outage data from ERCOT in Figure 5.⁷ In the spring weather prior to onset of the freeze, wind was providing as much as 50 to 60 percent of total power generated from the main sources (Figure 4, left). During the freeze, natural gas

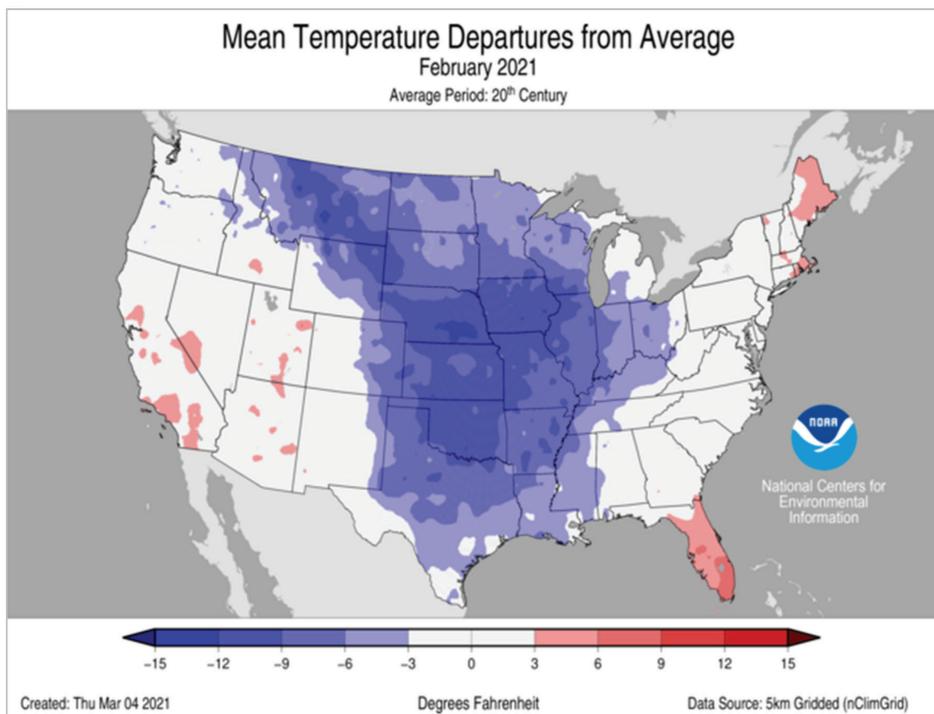
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Figure 1. The 2021 Winter Event



Source: NOAA, <https://www.ncdc.noaa.gov/sotc/national/202102>

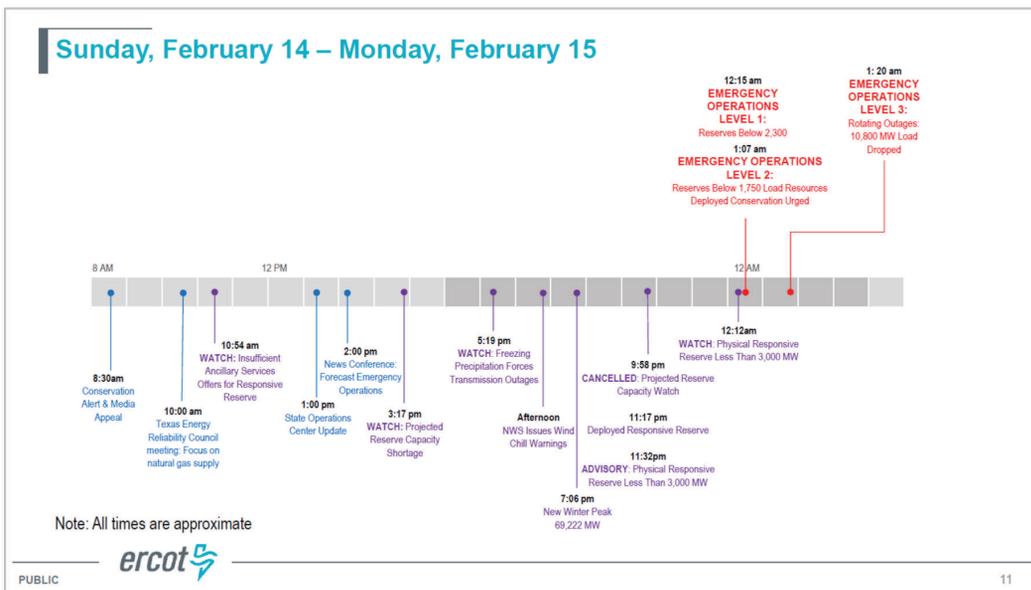
Figure 2. ERCOT Pre-event Communications

Pre-Event Communications	
November 5	ERCOT meteorologist issues winter outlook for Market Participants and public noting the "very good" chance for an extreme cold weather event during winter 2020/2021.
February 3	ERCOT meteorologist warns Market Participants and the public of coldest weather of the year. Weather updates continue.
February 8	Operating Condition Notice issued for extreme cold weather event, posted on public website.
February 10	Advisory issued for extreme cold weather event posted on public website. Issued grid conditions update for market media representatives.
February 11	Watch issued for cold weather event (hotline calls made, notice to Market Participants, posted on public website). News release on extreme weather expected, social media outreach.
February 12	Texas Energy Reliability Council meeting.
February 13	State Operations Center news conference: forecast Conservation Alert. Emergency notice issued for extreme cold weather event, posted on public website. Texas Energy Reliability Council meeting.
February 14	Issued conservation appeal by news release, performed social media outreach, held media briefing.

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Source: ERCOT, http://www.ercot.com/content/wcm/key_documents_lists/225373/2.2_REVISIED_ERCOT_Presentation.pdf.

Figure 3. ERCOT Preliminary Analysis of 2021 Winter Events, Sunday February 14 – Monday February 15



Source: ERCOT (see Figure 2).

fueled generation reached and exceeded 70 percent of total online capacity even with problems ranging from ice plugs in producing wells to equipment failures at processing and power plants. Coal plants were impacted by heavily iced storage piles of fuel.

Figure 6 below is the final image from a visualization of outages based on the same ERCOT timestamp data. Outages progressed generally from north to south with the storm track, placing pressure on wind first given the preponderance of facilities in the Texas Panhandle.

Crucially, the aggregation of generation outages while heating demand was affecting load meant a threat of complete grid failure. Early on February 15, frequency dropped below 60 Hz, "30 minutes of terror"

as units tripped off simultaneously. This stressful period is depicted in Figure 7. It may come to be viewed as the finest hour for the unheralded grid operators since by their quick action ERCOT was able to avoid a system-wide blackout.

Estimates of the death toll in Texas, the most severely affected state, are estimated to have exceeded 200. Fatalities of any number are the most tragic result of this crisis. Outages of municipal water systems and telecommunications worsened the experience for the entire state. Local utilities' lack of preparedness for such large curtailments, and their inability to rotate the ordered outages among their residential customers, turned a challenging grid situation into a public emergency.

During the event, the PUCT took actions to address issues related to problems that it believed were causing the market to function improperly. Following ERCOT's EEA

3 the PUCT issued an emergency order, on February 15,⁹ out of concerns that pricing was not reflecting the extreme conditions. The Commission's Chair stated that with the 10 GW of load shedding directed by ERCOT, scarcity pricing should be closer to the official \$9,000 per MWh price cap currently in place rather than the \$1,200 offer prices that the agency and ERCOT were seeing. Because generators were exceeding their maximum net margin revenue thresholds for peaking units, the PUCT suspended the low system-wide offer cap (the higher of \$2,000/MWh or 50 times the natural gas price) that would otherwise have kicked in. These actions reflected concerns about natural gas prices,

which had zoomed to nearly \$24 per million Btu (MMBtu) in the Henry Hub index on February 17.

These steps, as well as a later action, to extend the pricing at the \$9000 price cap until February 19, resulted

in severe economic impact to the market that continues to reverberate. ERCOT's review captures the impact as shown in Figure 8. Apart from the offer cap and clearing, some ancillary services charges exceeded \$20,000/MWh.¹⁰ Bankruptcies and lawsuits, constituting billions of dollars in losses, reflect the combined efforts to procure natural gas and ensure continuous grid operations.

The Learning Curve

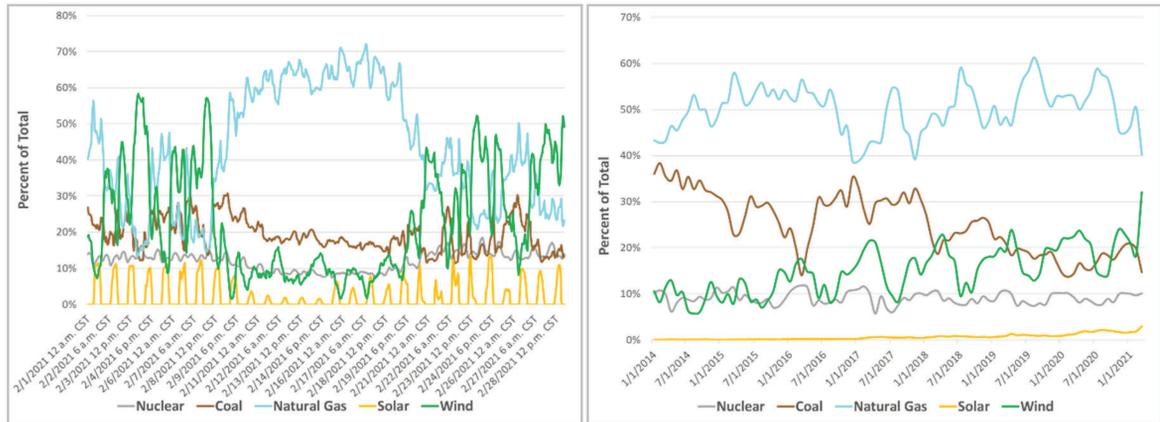
Evolution of the Texas competitive market has been well-documented.¹¹ Figure 9 is a snapshot of historical highlights for the U.S. and Texas. Current market rules and practices emanate from implementation of Texas Senate Bill 373 (1995)¹², Senate Bill 7 (1999)¹³ and opening of the fully competitive retail market on January 1, 2002 along with changes since then, such as moving from the initial zonal to the existing nodal wholesale market design on December 1, 2010.

The point of restructuring was to foster a highly transparent marketplace that could convey price signals, allowing the discipline of interacting buyers and sellers to inform decision-making.

As winter 2021 events unfolded, many issues resulting from a number of early decisions in Texas market design have been debated in the press and among commenters.

- Texas' unique retail choice design extends choice to residential customers and requires education about risks and uncertainties associated with retail providers and their plans. Clearly, some customers on unhedged wholesale products, such as those offered by Griddy and others, may not have understood those risks.
- The focus on an "energy only" nodal marketplace for wholesale competitive supply and pricing leads to questions about whether revealed prices are sufficient to ensure capacity and reliability during high demand periods, especially when the system is stressed.

Figure 4. ERCOT Electricity Generation by Source, February 2021 (left) and Monthly from 2014 (right) in MWh (top row) and Percent of Total Generation (bottom row)



Sources: EIA, https://www.eia.gov/electricity/gridmonitor/dashboard/electric_overview/US48/US48, as depicted by authors. Note that hydroelectric and other generation sources are small and excluded.

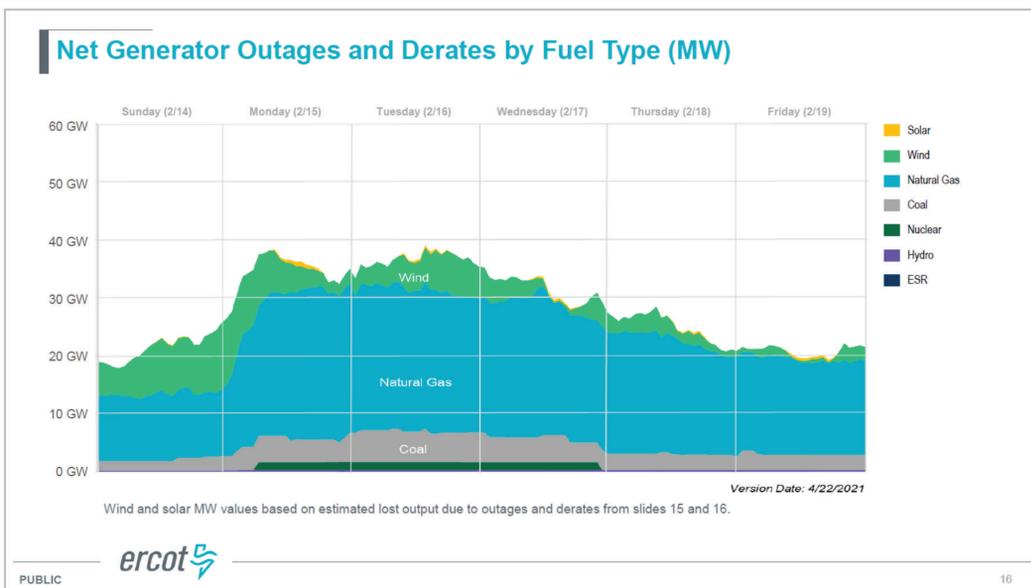
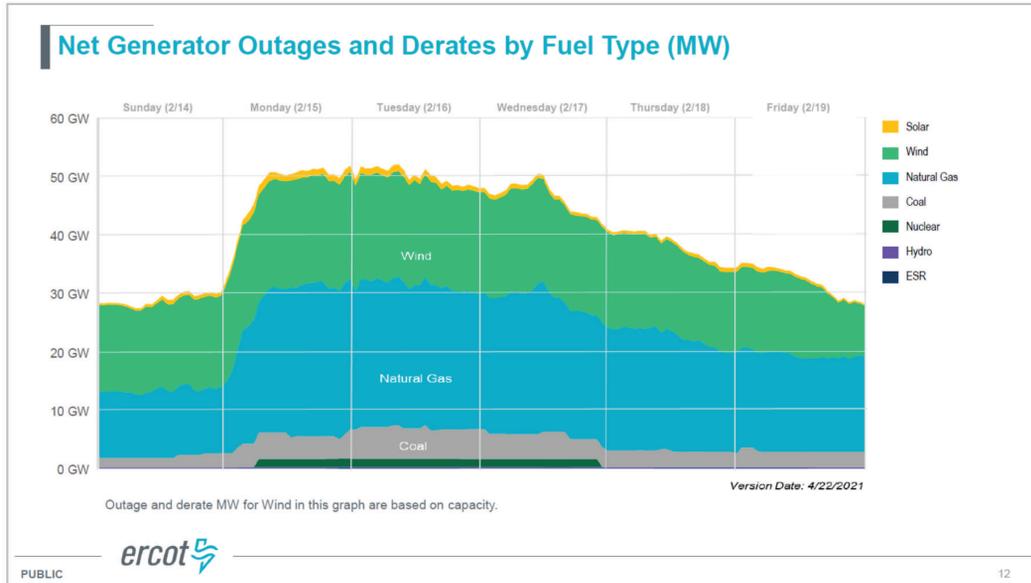
- Municipal utilities and cooperatives were free to decide whether to "opt in". This created a heterogeneous landscape of fully competitive resource entities co-existing with fully regulated ones. The costs of the event fell very differently on those in competitive and regulated part of the state.
- Fragmentation among the many different institutions that have stakes in the Texas marketplace – the PUCT, RRC, ERCOT, the Texas Reliability Entity (Texas RE, see previous Figure 9) along with federal bodies such as the Federal Energy Regulatory Commission (FERC) and North American Electric Reliability Council (NERC) and more, including local county and city governments and organizations, meant that no one entity had a true understanding of the complexity of the system
- In all, ERCOT remains a separate interconnection. Would interconnections to other U.S. regions have helped? Other parts of the region were facing similar stresses, so this widespread complaint, which surfaced early in the progression of the freeze, is difficult to assess.

Importantly, policymakers at the PUCT, the RRC, and the Legislature had warnings from prior incidents of large scale outages and associated reviews, in particular disruptions during winter 2011¹⁴, but left many recommendations insufficiently unaddressed. The 2011 outage involved about 5,000 MWs curtailed over a seven hour period as opposed to the much greater impacts experienced in February 2021. However, as one of us wrote in 2011¹⁵, failure of the industry to own up to root causes could lead to another major outage.

Wholesale Competition

Was Texas competitive market design a factor in the outage? One take is to compare performance between competitive and regulated resource entities. We separate "resource entities" that do not have wind or solar (with one exception as noted) from those that

Figure 5. ERCOT Outage by Source, February 14-19, 2021 in MW Based on Capacity (top) and Adjusted (bottom)



Source: ERCOT. Top chart reflects use of nameplate capacity as a baseline. Bottom chart reflects predicted available capacity for wind and solar without outages and derates.⁸

only engage in those products. We separate municipal utilities and electric cooperatives that remain fully regulated monopolies. The 12 resource entities used in Figure 10 represent about 60 percent of nameplate capacity within ERCOT. The result indicates a wide range of performance with respect to outages and, implicitly, underlying portfolios and management practices¹⁶. In general, the resource entities that remain fully regulated performed less well even excluding a strong outlier.¹⁷ For all resource entities the financial incentives to perform were very strong.

Pricing and Market Design

In the past decade, Texas has debated whether to institute a formal capacity market. A common argument has been that energy-only, real time pricing

cannot provide sufficient incentive for long-term investments.

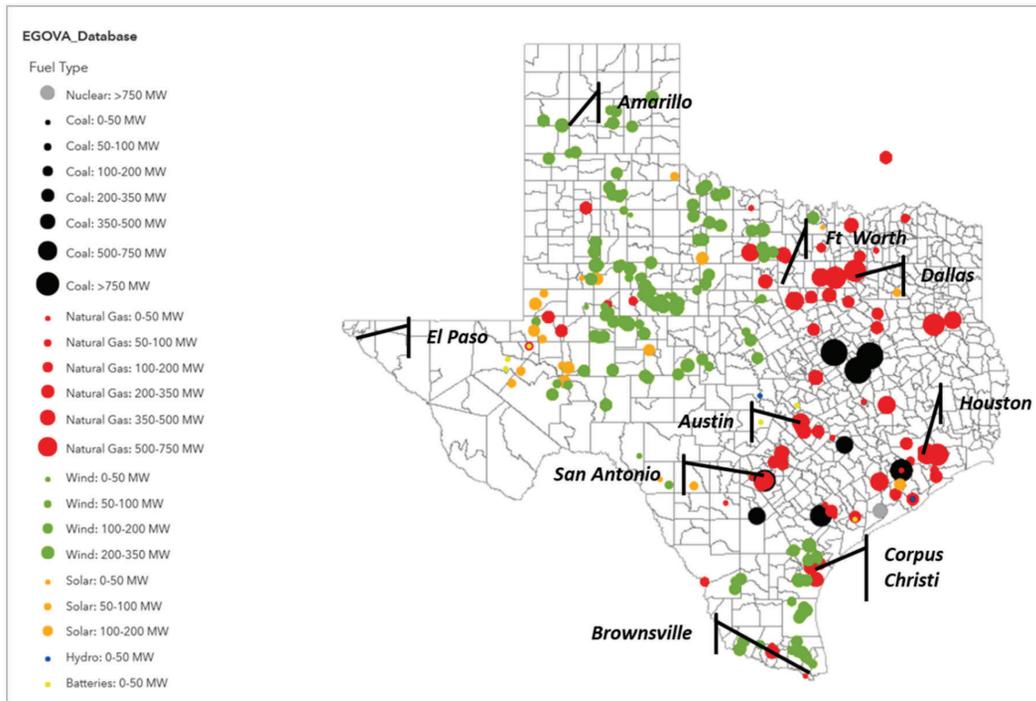
During February, ERCOT's issue was not the lack of capacity but rather that its *planned* capacity could not deliver due to *unplanned* outages. A capacity market could not have solved this problem as the 2014 "polar vortex" in PJM has shown. Moreover, the \$9,000/MWh price is much more powerful than penalties usually found in capacity market designs.

After the 2011 winter event, the PUCT adopted the operating reserve demand curve (ORDC) as a more surgical way to spur economic investment. The ORDC effectively adds a ramp-up in price to what would otherwise be a vertical price/demand curve. As demand approaches available capacity, an administrative adder is applied to the market clearing price to send an earlier, stronger price signal for demand to curtail and for supply to be available.

One factor affecting the robustness of the energy market is the volumetric production federal income tax credit given to wind energy. Much of Texas wind output receives a federal \$23/MWh production tax credit (PTC) subsidy. This is roughly the overall clearing price for power in the ERCOT energy market, making the federal subsidy material. As opposed to the solar investment tax credit, which is an offset to capital expense, the ongoing PTC is reflected in every MW-hour sold for ten years after a wind plant is built.

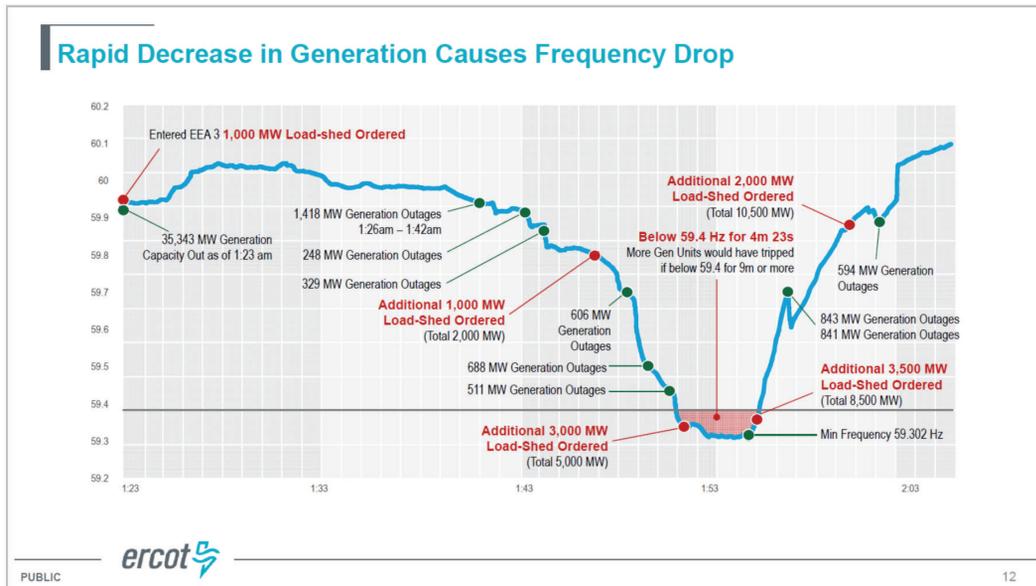
Arguments related to distortions associated with wind and PTC treatment are well trod ground.¹⁸ In any case, the jury is still out on whether the ORDC has resulted in new investment in new thermal generation and storage capacity.

Figure 6. Geospatial Map of ERCOT Outages and Derated Generators



Source: Edgar Virgúez, Duke University, ERCOT's Generator Outage/Derate Visualization App (EGOVA), <https://dukeuniv.maps.arcgis.com/apps/instant/media/index.html?appid=6080cf98448146168db92262ab7308d1>.

Figure 7. ERCOT Frequency During Event



Source: ERCOT (see Figure 2).

REPs and Their Products

The retail competitive market is a separate issue. Most retail customers choose bilateral fixed price contracts, providing predictability around pricing and cost. Almost all residential customers in the customer choice regions of the state were largely unaffected by the wholesale power costs of the February outage. Similarly, many commercial and industrial users had price protection through their negotiated contracts. The impact on their competitive providers, however,

varied widely, depending on how well those providers were able to manage procurement and hedge risk. Several REPs did not have the wherewithal to absorb high costs for power and ancillary services¹⁹ and represent some of the bankruptcies and litigation progressing through Texas courts. One such REP referenced earlier, Griddy, received considerable notoriety²⁰ because its roughly 10,000 customers chose to be directly exposed to wholesale market pricing as compared to roughly seven million statewide that use fixed rate contracts from other REPs.

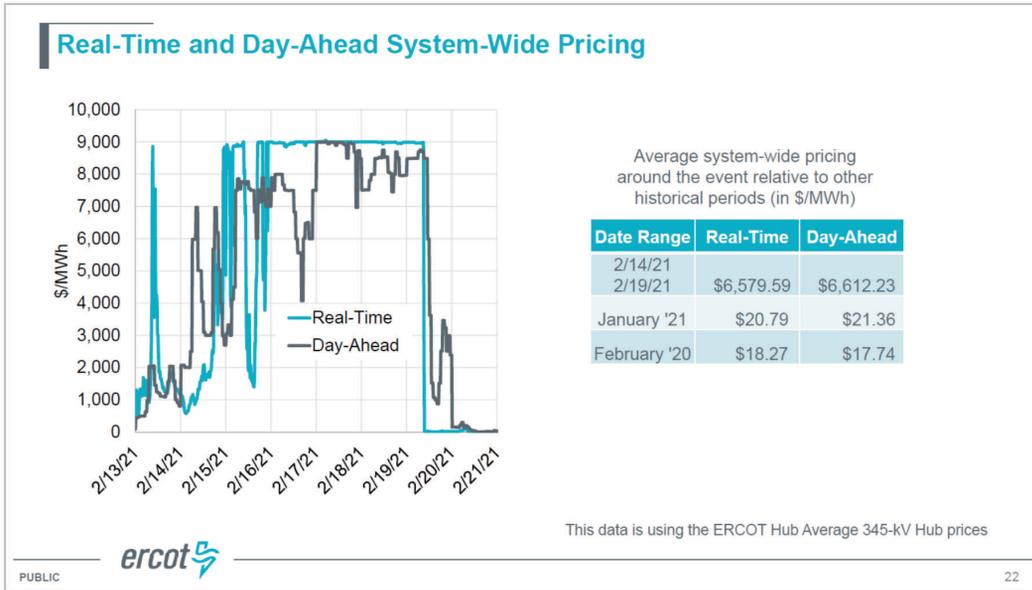
In contrast, regulated municipal and cooperative monopolies, which serve about one-sixth of ERCOT customers, almost certainly will be allowed to pass through most or all of their fuel and power costs to their captive ratepayers. The Texas Legislature passed laws enabling the securitization of such costs at lower interest rates by electric cooperatives and regulated gas distributors for up to 30 years. So there is a difference in how risk

is borne in competitive and regulated retail markets.

Operational Dilemmas

Operational challenges are the first problems to solve. Past experience during previous outages in 2011, 2003 and before should provide lessons. As we suggested earlier, they may also offer low hanging fruit in possible fixes that were identified, such as during the 2011 review, but not yet implemented. The winter

Figure 8. Winter Storm Impacts on Pricing



Source: ERCOT (see Figure 2).

2021 event represented a significant loss of supply from the statewide pool, and a much lesser than expected outage due to iced-over poles and wires, making it unusual.

The harsh lesson from these experiences is the need to learn to expect unexpected, plan for unexpected, and be able to make systems work through events no one expects. None of this is easy, but a first step is to identify and work on what was inoperable. For the 2021 experience, the natural gas system is a place to start.

Natural Gas and Gas-Electric Harmonization

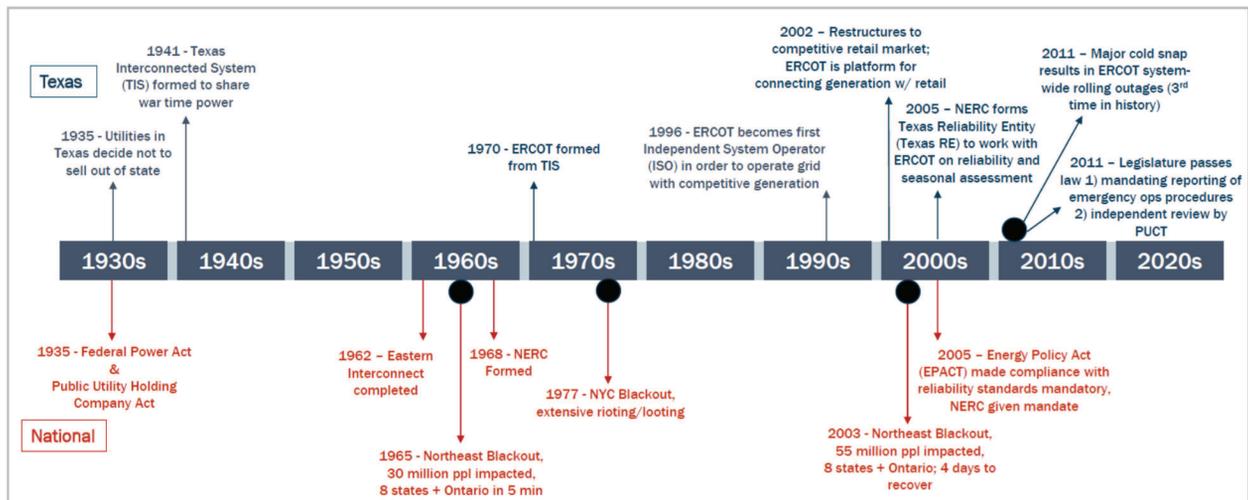
The preponderance of outages in Texas, including significant events, are during winter. And yet, for obvious reasons, most of the planning and focus in ERCOT has been on hot summer months. Natural gas prices are a clue to relative stress. With some

exceptions, hot weather and hurricanes have much less impact on gas supply and pricing than winter shortages (Figure 11). Rapid escalation in natural gas prices and costs are felt across the U.S. as diminished flows in interstate pipelines remove gas from end use markets. Based on industry information, interstate pipeline throughput dropped by as much as 80 percent in some cases.

Many unanswered questions persist about the performance of the natural gas system during the February event. Reports of delivered gas costing several hundreds of dollars per MMBtu, orders of magnitude above normal winter pricing, raise red flags.²¹ Sharp increases in price mainly are symptomatic of bottlenecks, of which there were many. It can also be that the boundaries lie around who had gas to sell, with ability to ship and deliver it, and whether receiving customers had contracted sufficiently for their fuel resources in advance.

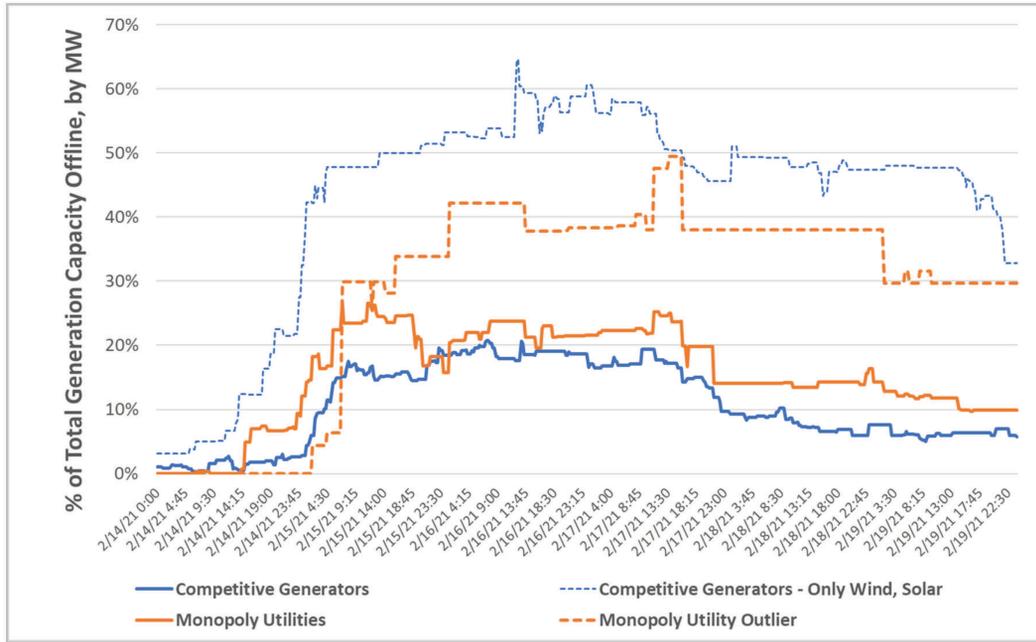
Deeper questions revolve around the very strong interplay between natural gas, which supplies well over half of ERCOT power generation at peak and on an annual basis, and electric power. These are two very different systems – an extremely transparent five minute, around-the-clock market for power and grid balancing in contrast with a gas industry which

Figure 9. Evolution of the Texas and U.S. Electric Power Systems



Source: Greater Houston Partnership, <https://vimeo.com/519628142>.

Figure 10. Outage by Types of Resource Entities

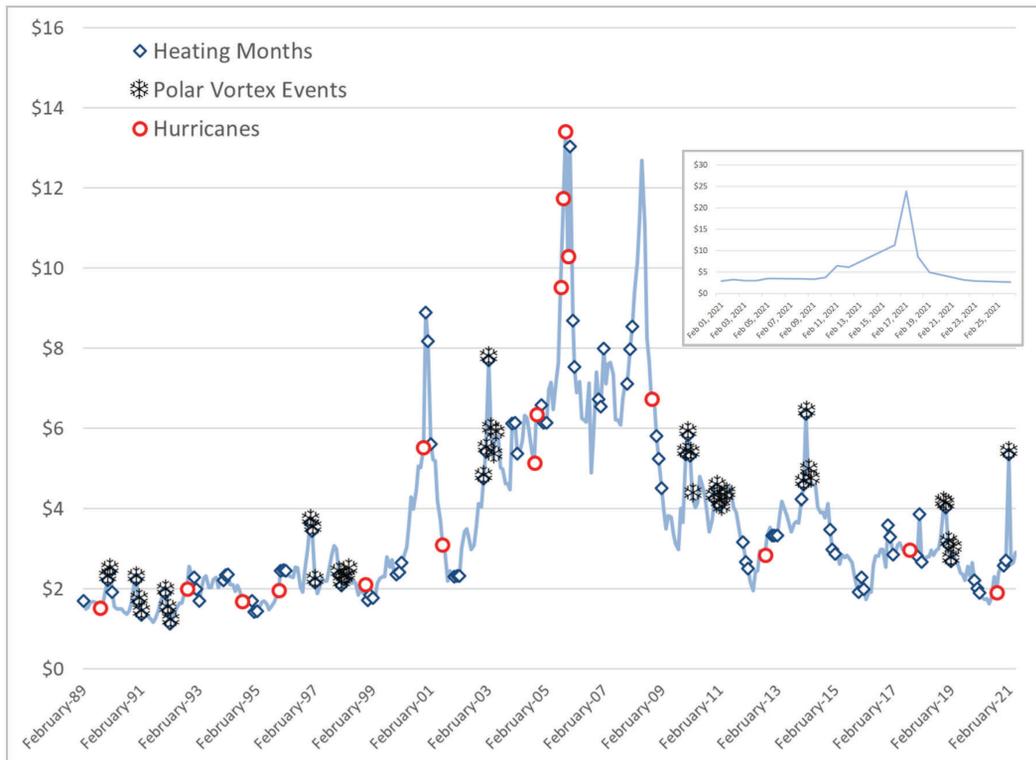


Source: ERCOT for generation, nameplate capacity from various sources, as depicted by authors. Note –“Competitive Generators” includes one entity with wind assets constituting four percent of its Texas portfolio for which no outage was reported.

operates five days a week during business hours with no night trading, and month ahead nominations for pipeline capacity to deliver supply. Among the lowest hanging fruit is greater awareness among utilities that natural gas is critical fuel for their generation.

delivery system.²⁴ Experiments with other approaches for producing fields are still nascent. Unknown is the effect of the \$9,000 price cap on these practices going forward. At the minimum, standalone, backup power supply would offset risks from interdependencies.

Figure 11. Henry Hub Weather Events



Sources: CME/NYMEX from EIA, NOAA, National Bureau of Economic Research and various news outlets, compiled by authors.

Oncor, the state’s largest utility, pre-event, had classified 35 gas facilities as critical (and therefore not to be curtailed during any controlled outages). Post event, Oncor added an additional 168 facilities to the list.²²

The trick is how best to integrate two such different industries and systems as much as possible.²³

One underlying factor has been the trend toward using grid-based electricity, made cheap by abundant low cost natural gas, to provide energy for field operations and the natural gas

Weatherization

Weatherization is a system issue related to natural gas, although plenty has been written elsewhere regarding wind, coal-fired and gas-fired power generation facilities. Recommendations for winterizing natural gas production and midstream were made in the 2011 post-event report. Estimates on the cost of weatherization down to the wellhead vary widely with some reports indicating that it can be done cost effectively and others indicating that it can double the cost of completions.²⁵ A recommendation for exemptions from

rolling blackouts for critical natural gas facilities has struck a chord given confusion last February regarding the RRC and electric utility process for making and fielding these requests.

Planning

What steps could have been taken to better prepare the public?

Given that the larger, more widespread outage events occur in winter, a “hurricane level” of preparedness could become the norm. Images of brightly lit commercial buildings when households were without power (or water or telecoms and internet) grated. A more granular system to manage rolling outages could address what became, ultimately, a public safety catastrophe.

What of the key institutions? As we complete this article, the Texas Legislature – which meets every two years – has passed legislation to address some of the key issues raised by the February outage. After an initial flurry of proposals, bills²⁶ related to the outage settled into more pragmatic approaches to improve emergency preparedness (alerts and backup power at health facilities), mandate winterization for power plants and natural gas facilities, and allow ratepayer-backed bonds and loans for gas and power companies. As the winter freeze tightened its grip, ERCOT governance came under immediate scrutiny. A smaller, but now fully independent, ERCOT board will be selected by a trio of political appointees. Regulators must now review whether sufficient reserves are available for wind and solar or if more are required.

Should all of the infrastructure industries come under one regulatory roof? As attractive as this idea might be for within-state planning and coordination, it is unlikely.

What of the federal jurisdiction? The Texas RE remains controlled by NERC and Texas remains a NERC electric reliability organization (ERO)²⁷. In 2005 mandatory reliability standards were made applicable across all of the U.S. No carve out for Texas or ERCOT was granted. The Texas RE, charged with monitoring compliance with mandatory standards, was broken out of ERCOT to ensure independence and is being

deployed by FERC and NERC for their investigation of 2021 events.

Positioning for the Future

In all, the 2021 winter storm represents classic tail risks and associated economics – high consequence but low probability events, expensive to “insure” against. However, with at least three major events over the last two decades (2003, 2011, 2021), it is becoming increasingly clear that these are not classic tail events and that policymakers must act to address what has become common occurrence.

A related, and perhaps even more intriguing issue, is the implication from the 2021 experience for the state’s, and nation’s, energy future: how to balance the imperative for using the grid as a tool for decarbonization while maintaining high levels of reliability.

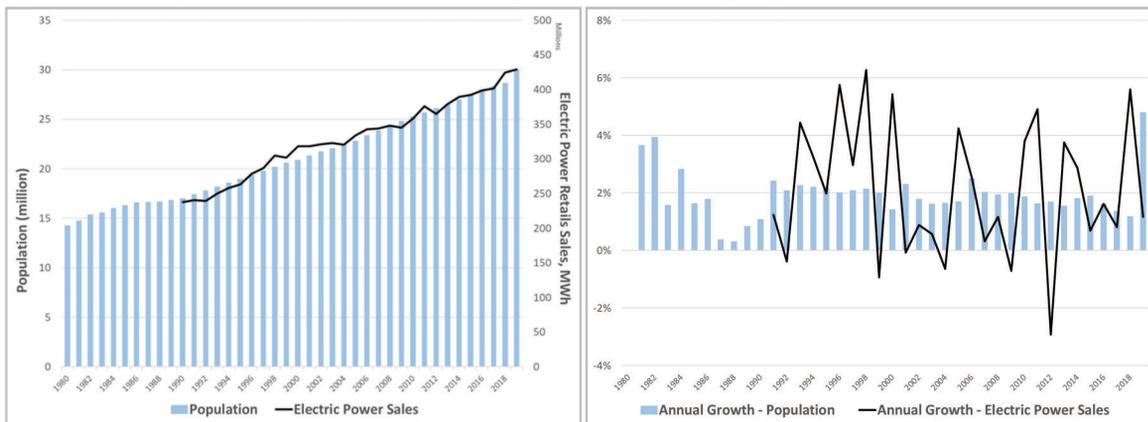
In its 2020 report on reliability²⁸ NERC pointed to the assorted risks emanating from increased investment in wind and solar facilities. These generation resources have variable output and performance, and government subsidies can distort energy market pricing. Still, they are expected to increase in share of power capacity and production, although there is some public opposition to essential transmission improvements. Wind, solar, batteries, electric vehicles represent geopolitical exposure stemming from international supply chain risks and disruptions.

Let it be said – Texas is a big state, attracting migrating businesses and residents on a net basis every year. Population and electric power demand have grown in tandem, but year to year changes in electricity sales reflect recessions and other events that encumber electric power planning. One of the more significant differences across historical outage events is simply the larger number of people, households and businesses that are impacted over time.

Even as Texas adds new sources of generation, the challenge is to figure out how to facilitate the flow of wind, solar and storage while ensuring reliability during the hottest summers and coldest winters. Fossil fuels and nuclear are too important to dismiss. In an intriguing mandate to the PUCT to study and act on

dispatchable generation, the Texas Legislature recognized the need to plan for the future with these resources in mind.²⁹ High demand periods lead to financial consequences that cannot

Figure 12. Texas Population and Electric Power Sales (left) and Year-Year Change (right)



Sources: U.S. Census Bureau and EIA, compiled by authors.

be minimized, otherwise power systems are not economically sustainable. New technology is desirable – smart meters, distributed energy resources like rooftop solar, flexible energy storage and much more. The challenge is to enable these attractive technologies to more fully enhance reliability.

No models exist in any part of the world to guide development of the power grids of the future. Texas is the front line, making the learning curve an imperative.

Footnotes

¹ Refer to U.S. National Oceanographic and Atmospheric Administration, NOAA, recap, <https://www.ncdc.noaa.gov/sotc/national/202102>.

² Based on tracking of commercial weather news from Enelyst, a free chat service for energy and weather trading desks, <https://www.enelyst.com/tryitnow.html>.

³ ERCOT Board video, Feb. 9, 2021 available at <https://ercot.new.swagit.com/videos/112718> (at 27:16).

⁴ Extracted from <https://www.rrc.state.tx.us/gas-services/texas-energy-reliability-council/>.

⁵ Since the 2003 winter storm event, there has been a need for the RRC to update its 1973 curtailment priorities. See recommendation for the PUCT to “collaborate with the RRC to determine a joint curtailment methodology for natural gas and electricity” https://www.puc.texas.gov/industry/electric/reports/ERCOT_annual_reports/special_weather_event.pdf.

⁶ For information on ERCOT’s emergency operations levels and responses see http://www.ercot.com/content/wcm/lists/164134/EEA_OnePager_FINAL.PDF. Of note is that, prior to the winter storm event in February 2021, ERCOT had initiated system-wide rotating outages three times in its history, “Dec. 22, 1989, April 17, 2006 and Feb. 2, 2011”.

⁷ See ERCOT’s Update to April 6, 2021 Preliminary Report on Causes of Generator Outages and Derates During the February 2021 Extreme Cold Weather Event, April 27, http://www.ercot.com/content/wcm/lists/226521/ERCOT_Winter_Storm_Generator_Outages_By_Cause_Updated_Report_4.27.21.pdf.

⁸ See A. Kumler et al 2019 Environ. Res. Lett. 14 044032, <https://iopscience.iop.org/article/10.1088/1748-9326/aaf935> for excellent analysis of wind and solar variability (ERCOT case study).

⁹ The PUCT order is at <https://www.puc.texas.gov/51617WinterERCOTOrder.pdf>. Also see J.P. Casey, “Texas to raise energy prices and suspend price cap amid winter storm” in Power Technology, February 18, <https://www.power-technology.com/news/texas-to-raise-energy-prices-and-suspend-price-cap-amid-winter-storm/>. A follow up order on February 18 directed transmission and distribution utilities – excluding municipal and cooperative entities – to rotate outages. <https://www.puc.texas.gov/51812WinterRotationOrder.pdf>.

¹⁰ For a typical complaint see “Texas REP Asks PUC To Re-Price Scarcity Prices Since Feb. 15 To \$1,500 For Energy, \$500 For Ancillary Services”, Energy Choice Matters, February 19, <http://www.energychoicematters.com/stories/20210219ah.html>. For typical news media coverage “Even Texans with fixed electricity plans may face high energy costs due to this fee” by H. Samsel, Fort Worth Star Telegram, March 8, <https://www.star-telegram.com/news/business/article249728743.html>. The ERCOT Independent Market Monitor, IMM, Potomac Economics recommended that the PUCT direct ERCOT to correct real time prices to remove the adder charged by ERCOT for the additional 32 hours as referenced in the example complaint. See https://interchange.puc.texas.gov/Documents/51812_61_1114183.PDF.

¹¹ Some good references are: *Electricity Reform and Retail Pricing in Texas*, P. Hartley, K. Medlock, O. Jankovska, 2017-2019, <https://www.bakerinstitute.org/research/electricity-reform-and-retail-pricing-texas/>; *Deregulated Electricity in Texas: A Market Chronicle (20th Anniversary Edition)*, R.A. Dyer, 2019, <https://www.amazon.com/Deregulated-Electricity-Texas-Chronicle-Anniversary/dp/1695430492>, various editions and years produced through the Texas Coalition for Affordable Power,

<https://tcaptx.com/industry-news/new-report-tcap-updates-signature-history-of-deregulation-chronology>; *Net Social Cost of Electricity*, G. Gülen, 2019, <https://store.beg.utexas.edu/special-books/3777-us0007-net-social-cost-of-electricity.html>; *Electricity Restructuring: The Texas Story*, ed. L. Kiesling and A. Kleit, 2009, <https://www.amazon.com/Electricity-Restructuring-Lynne-L-Kiesling/dp/0844742821>; *Electric Choices: Deregulation and the Future of Electric Power*, ed. A. Kleit, 2006, <https://www.amazon.com/Electric-Choices-Deregulation-Future-Power/dp/0742548767>; *Guide to Electric Power in Texas*, Third Edition, 2003, https://www.beg.utexas.edu/files/cee/legacy/guide_electric_power_texas_2003.pdf.

¹² See <https://capitol.texas.gov/billlookup/History.aspx?LegSess=74R&Bill=SB373>.

¹³ See <https://capitol.texas.gov/billlookup/History.aspx?LegSess=76R&Bill=SB7>.

¹⁴ *Report on Outages and Curtailments During the Southwest Cold Weather Event of February 1-2, 2011*, <https://www.ferc.gov/sites/default/files/2020-04/08-16-11-report.pdf>. Also see B. Perlman, “Who caused the blackout?”, Dallas Morning News, February 24, 2011, available from <https://www.centerforhoustonfuture.org/news-and-media/2011/2/24/dallas-morning-news-op-ed-by-brett-perlman-who-caused-the-blackout>.

¹⁵ See Perlman, endnote 12

¹⁶ For instance, “‘Caught flat-footed’: Energy experts, lawsuits claim CPS has itself to blame for \$700 million in natural gas bills”, D. Collier and J. Saunders, KSAT News, April 7, <https://www.ksat.com/news/defenders/2021/04/08/caught-flat-footed-energy-experts-lawsuits-claim-cps-has-itself-to-blame-for-700-million-in-natural-gas-bills/>.

¹⁷ In his comments during the FERC *Technical Conference to Discuss Climate Change, Extreme Weather, & Electric System Reliability*, June 2, David Patton, President, Potomac Economics stated that “we saw much bigger problems with public entities than we did with competitive retail loads or the competitive generators”. Potomac Economics serves as the independent wholesale market monitor for ERCOT and other grids. For information and recordings, <https://www.ferc.gov/news-events/events/technical-conference-discuss-climate-change-extreme-weather-electric-system>.

¹⁸ See C. Pirrong, “How low can prices go?”, Streetwise Professor, February 18, <https://streetwiseprofessor.com/how-low-can-prices-go-and-why/> and Gülen, endnote 10. Texas wind helps to place the United States second to China (roughly 122 to 288 gigawatts or GW) and Texas alone (31 GW) is ahead of fifth place Spain (27 GW), using the latest rankings from Ns Energy, <https://www.nsenenergybusiness.com/features/top-countries-wind-energy-capacity/>

¹⁹ See previous endnote 9.

²⁰ “Texas power retailer Griddy heading for bankruptcy - Wall Street Journal”, G. McWilliams, Reuters, March 14, <https://www.reuters.com/world/us/texas-power-retailer-griddy-heading-bankruptcy-wall-street-journal-2021-03-14/>.

²¹ See “Opinion: We helped design ERCOT, here’s how to prevent another major Texas electricity failure” by a group of former regulators including the two co-authors here, June 4, Houston Chronicle, <https://www.houstonchronicle.com/opinion/outlook/article/Opinion-We-helped-design-ERCOT-here-s-how-to-16225130.php> and recommendations <https://cgmf.org/blog-entry/435/REPORT-%7C-Never-Again-How-to-prevent-another-major-Texas-electricity-failure.html>.

²² See “Paperwork failures worsened Texas blackouts, sparking mid-storm scramble to restore critical fuel supply”, E. Douglas, The Texas Tribune. <https://www.texastribune.org/2021/03/18/texas-winter-storm-blackouts-paperwork/>.

²³ The North American Energy Standards Board, NAESB, will again take up the issue of standardized practices for natural gas and electric wholesale operations with FERC in the mix.

²⁴ In their 2011 report, FERC and NERC staff found that nearly one-third of natural gas production shortfalls in the Fort Worth and Permian basins were due to curtailments of producers. The staff also found that gas supply shortages were less a factor for power generators than severe weather conditions. Endnote 11 for link.

²⁵ See "Touching the Third Rail: The Dangers of Electricity Market Design". C. Pirrong, Streetwise Professor, February 21, <https://streetwiseprofessor.com/index.php?s=weatherization>. This view is compatible with a wide range of opinions from oil and gas operators. An alternative view suggesting much lower costs comes from G. Golding, A. Kumar and K. Mertens, "Cost of Texas' 2021 Deep Freeze Justifies Weatherization", Dallas Fed Economics, <https://www.dallasfed.org/research/economics/2021/0415.aspx>.

²⁶ "Texas Legislature approves bills to require power plants to "weatherize," among other measures to overhaul electric grid" by E. Douglas

and M. Freeman, The Texas Tribune, May 30, <https://www.texastribune.org/2021/05/26/texas-power-grid-reform-legislature/>.

²⁷ See <https://www.nerc.com/AboutNERC/keyplayers/Pages/default.aspx> for NERC EROs.

²⁸ See https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_LTRA_2020.pdf. ERCOT's nodal protocols, <http://www.ercot.com/mktrules/nprotocols/current> are an example of complexity.

²⁹ See Texas SB 3, 2021-2022, section 18, <https://legiscan.com/TX/bill/SB3/2021>.