

The 2021 Texas Blackouts: Causes, Consequences, and Cures

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ABSTRACT

In February 2021, rolling blackouts in Texas during Winter Storm Uri demonstrated the vulnerability of the State's electric grid managed by the Electric Reliability Council of Texas (ERCOT). This article examines the technical causes of the ERCOT blackouts, financial and human consequences, and policy changes that could prevent recurrences. ERCOT planned for a winter load peak far below actual electricity demand. Further electricity shortfalls were caused by generation plants with varied energy sources becoming unavailable—natural-gas fired, coal-fired, nuclear, wind, and solar. Prior blackouts during a 2011 period of cold weather had shown the need for better resource planning and plant weatherization, but advance preparation was inadequate. The system of compensating generators in ERCOT was market-based with a \$9,000 per megawatt hour cap on wholesale electricity rates—a so-called “Energy-Only market.” This regulatory system did not provide adequate incentives for generation plants to be operational during extreme weather, nor did it ensure that natural gas suppliers could deliver fuel to generators. Texas is well-situated for a return to the cost-of-service regulatory model; the State Legislature should consider this policy option.

Keywords: Texas, ERCOT, Electric Grid, Blackout, Uri

Introduction

The State of Texas has its own electric grid, distinct from the Eastern and Western Interconnections that serve most of the continental United States and parts of Canada. Because the Texas electric grid has only a few low-capacity connections with other states, it is not subject to federal regulation of its transmission lines and tariffs. Accordingly, Texas was able to establish America's first electricity market in

1995, two years before Order 888 of the Federal Energy Regulatory Commission (FERC) enabled electricity markets for other U.S. States.

Electric power for most of the land area and population of Texas is supplied by an electricity market managed by the ERCOT. ERCOT is a quasi-governmental nonprofit that sets market rules, conducts daily auctions to determine wholesale electricity prices, and settles accounts between generators and retail distributors. ERCOT also serves as a balancing authority that dispatches generation to balance electricity supply with customer load. The customer load managed by ERCOT is approximately 90% of total electricity consumed in Texas, the remainder being consumed in areas near the state's border served by the Eastern and Western Interconnections.

The ERCOT market is distinctive among U.S. electricity markets in that it is "Energy-Only." An Energy-Only electricity market relies entirely on market forces to ensure both reserve generation capacity and real-time production of electric energy. In contrast, other areas of the U.S. use so-called "capacity markets" in addition to real-time markets or, alternatively, administrative planning processes to assure that sufficient generation capacity exists to avoid shortages during normal and extreme conditions.

Starting on Sunday, February 14, 2021, the Texas region experienced unseasonably cold weather. Temperatures in Austin (approximately the geographic center of the state) plunged to 9 degrees Fahrenheit that evening and remained below freezing until the following Friday. In Texas both fossil fuel-fired plants and wind turbines are generally not designed for extended periods of cold weather. Additionally, because Texas has a moderate climate, homebuilders have found it cost-effective to install resistive heating as standard practice—a heating method that draws large amounts of grid electricity during rare cold spells.

During the week of February 14, fossil fuel-fired generation plants, fuel supply infrastructure, and wind turbines experienced temperature-related malfunctions. In order to maintain internal temperatures, homes and businesses consumed far more electricity than normal in winter. This combination of generation plant freeze-ups and higher electricity demand caused ERCOT to order rolling blackouts from Monday, February 15 until Thursday, February 18. At the peak of the blackouts on February 15, approximately one-third of ERCOT electricity consumers were without electricity. (PowerOutage.US, February 2021)

The severity of the blackouts demonstrated that the electricity sector in Texas had not adequately planned for extreme cold weather like Winter Storm Uri. But an event of this type should have been reasonably anticipated. In February 2011, cold weather hit the Southwestern United States, resulting in freeze-ups and other malfunctions at 210 generating plants in ERCOT. Grid operators ordered a load shed of 4,000 megawatts, resulting in rolling blackouts for 3.2 million elec-

tricity customers (FERC, August 2011). Despite that experience, state regulators and utilities did little to weatherize the Texas electric grid.

Generation Planning

ERCOT and its regulator, the Public Utility Commission of Texas (PUCT), do not set requirements for specific generation resources, but instead rely on market forces to determine types of generation and their installed nameplate capacities.¹ Under the Energy-Only market model, regulators allow electricity prices to rise far above normal day-to-day levels as an incentive for utilities to invest in capacity that will remain unused much of the time. This high region of prices is referred to as “Scarcity Pricing.”

The Scarcity Pricing Mechanism in ERCOT is defined in Texas Administrative Code §25.505. The price is set at one of two levels depending on “Peaker Net Margin” (PNM). PNM is a mechanism used by the PUCT in an attempt to balance the need to ensure that generators make enough profit to be financially attractive, but also not overly burdensome on consumers. PNM is set to zero at the beginning of the calendar year and then increases throughout the year depending on market prices. Until the threshold PNM value is achieved, the Systemwide Offer Cap is set at the High value (HCAP); once the threshold value is achieved the Systemwide Offer Cap is reset to the Low value (LCAP). In many years, the threshold PNM value is not achieved.

Prior to 2021, the HCAP was administratively raised several times until it reached \$9,000 per megawatt-hour. The wholesale price of electricity in ERCOT for 2020 was generally \$20-30 per megawatt-hour. ERCOT and the PUCT calibrate the amount of the “price cap” via economic analysis and statistical methods to incent capacity reserve margins of about 10-15%—a process that is inherently indirect and inexact. The regulatory structure in Texas had judged these reserve margins adequate to prevent blackouts except for a small number of hours each ten years (Schneider, 2020).

ERCOT is considered to be a “summer peaking” system. For summer 2020, ERCOT forecasted peak load of 75,200 megawatts while it forecast 57,699 megawatts for winter 2020-2021 (ERCOT, 2020). Much of ERCOT’s attention in setting an appropriate price cap has been devoted to ensuring adequate summer generation capacity. It is notable that the price caps set by ERCOT have not been designed to vary by season while the planning process and projected reserve margins are different for winter and summer. There are no explicit capacity planning processes

1 According to the Glossary of the U.S. Energy Information Administration, “Generator nameplate capacity (installed)” is defined as “The maximum rated output of a generator, prime mover, or other electric power production equipment under specific conditions designated by the manufacturer. Installed generator nameplate capacity is commonly expressed in megawatts (MW) and is usually indicated on a nameplate physically attached to the generator.”

within ERCOT for the so-called shoulder seasons—spring and fall—when electricity demand is normally lower. With the exception of plant outages for planned maintenance, normally conducted in the shoulder seasons, the available capacity in ERCOT is similar in all seasons.

ERCOT uses a two-step planning process for seasonal generation resources. In the first step, nameplate capacity of thermal plants is tabulated, along with derated capacity of intermittent renewable resources and imports. For wind generation, 19% to 43% of nameplate capacity is tabulated, depending on installed region. Although Texas is at a low latitude compared to other parts of the U.S. and therefore receives more intense sunlight (absent cloud cover), solar generation accounts for only 0.4% of tabulated capacity.

Figure 1 shows generation resources planned to be available during the winter of 2020-2021 as part of the first step of ERCOT's Seasonal Assessment of Resource Adequacy (SARA). The vast majority of capacity in ERCOT consists of natural gas-fired plants. Other significant sources of thermal generation include coal-fired and nuclear. There are four nuclear reactor units in ERCOT: two at the South Texas Project and two at Comanche Peak Nuclear Power Plant. Wind turbines are also a significant generation resource in Texas, with good wind conditions in the Coastal, Panhandle, and West Texas regions (West Texas is designated as "Wind-Other" in the ERCOT planning process). Hydroelectric and biomass generation have small capacities in Texas, accounting for 0.5% percent of winter capacity. Because the ERCOT balancing area is unsynchronized with the Eastern and Western Interconnections, imports are constrained to a few High Voltage Direct Current (HVDC) transmission lines and represent less than one percent of winter capacity (ERCOT, 2020).

In the second step of ERCOT's planning process, derating is applied to thermal generation plants so that all resources have deratings. Figure 2 compares final derating factors used in the ERCOT winter planning process. Texas can have frequent cloud cover in winter; accordingly, solar resources are derated to 7% of nameplate capacity. Wind resources in ERCOT are derated by region: 43% for Coastal, 32% for Panhandle, and 19% for what is predominantly West Texas ("Wind-Other"). Hydroelectric generation is a small seasonal resource in ERCOT, heavily derated at 54%. The derating for thermal plants (natural gas-fired, coal-fired, and nuclear) is 81%; their derating factor accounts for maintenance outages ("planned outages") and mechanical malfunctions ("forced outages").

In the ERCOT planning process—and other electric grid planning processes that use single point derating factors—the derating factors represent probabilistic means (or averages) of expected performance. Generation technologies can experience a range of conditions that cause actual electricity production to be well below derated capacity. For example, when the wind is not blowing on the Texas coastline, the effective derating factor will be zero percent, not 43%. Likewise, when

the sun sets, the effective derating factor for solar generation is not 7%, it is zero percent. Grid planners in ERCOT and elsewhere are tempted to make optimistic assumptions that diverse generation technologies will not be impacted by the same event at the same time, but these assumptions are often not supported by logic nor experience. The fallacy of ERCOT’s optimistic planning assumptions became clear when thermal plants and wind turbines froze up simultaneously in February 2021.

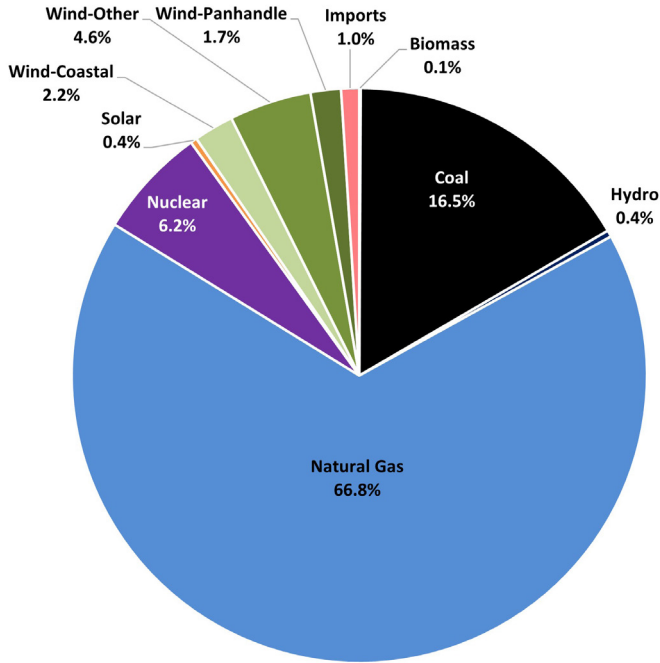


Figure 1. Winter 2020-2021 Seasonal Resources in ERCOT of 83 GW Total

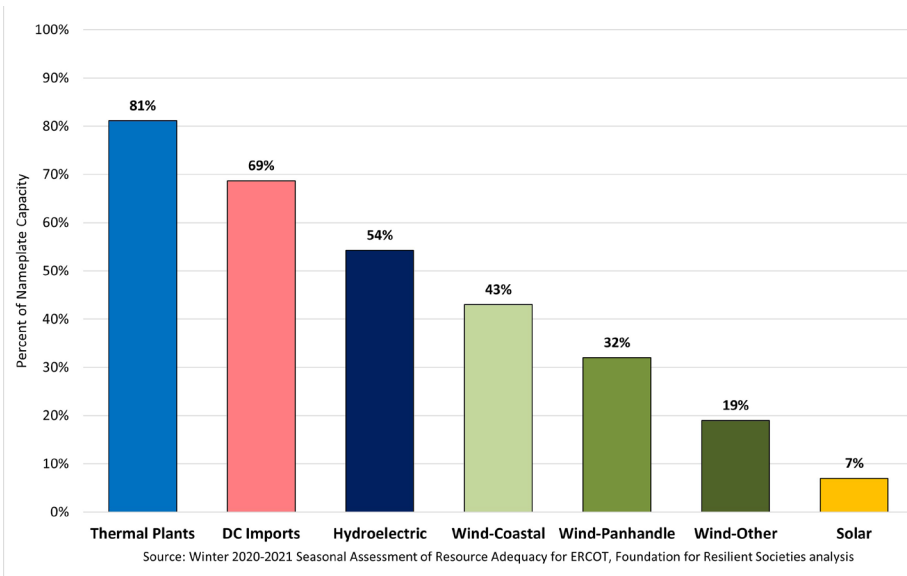


Figure 2. Derating Factors for ERCOT Winter Resource Planning

Sequence of Events

As early as February 8, a full week before rolling blackouts began in ERCOT, grid operators expected extreme conditions. “This statewide weather system is expected to bring Texas the coldest weather we’ve experienced in decades,” said ERCOT President and CEO Bill Magness in a news release. “With temperatures rapidly declining, we are already seeing high electric use and anticipating record-breaking demand in the ERCOT region” (ERCOT, 2021).

The ERCOT regulator, the PUCT, issued its own news release on February 11. “While people often associate the dog days of summer with high electricity consumption, plummeting temperatures predicted for the next few days will place significant demand on the ERCOT grid,” said Chairman DeAnn Walker in the release. “The electric system response under stress will, as always, require significant coordination between the Commission, ERCOT, and all entities responsible for providing safe and reliable power” (PUCT, 2021).

In Texas, the natural gas transmission and distribution system is regulated by the Railroad Commission of Texas (RCT). With two-thirds of ERCOT generation being gas-fired, the RCT issued an order on February 12 to reprioritize allocation of gas supplies. Under normal conditions, electric generators with interruptible contracts have fifth (and last) priority after residences and other “human needs” customers, industrial and commercial loads, factories, and operators of gas-fired boilers. The RCT order moved electric generators up to second priority, despite the lower rates (in normal times) paid by generators with interruptible contracts (RUT, 1973) (RUT, 2021).

On February 14, temperatures fell in Texas. As forecast, electricity demand increased as many homes and businesses turned on resistive heating. “We are experiencing record-breaking electric demand due to the extreme cold temperatures that have gripped Texas,” said ERCOT CEO Bill Magness in a 9:50 a.m. news release. “At the same time, we are dealing with higher-than-normal generation outages due to frozen wind turbines and limited natural gas supplies available to generating units. We are asking Texans to take some simple, safe steps to lower their energy use during this time” (ERCOT, 2021).

ERCOT reliably operated its system throughout the day of February 14, but conditions degraded soon after midnight. At 12:12 a.m. on February 15, electricity reserves dropped to less than 3,000 megawatts. Three minutes later, reserves dropped below 2,300 megawatts, initiating “Emergency Operations Level 1.” At 1:07 a.m. reserves, dropped below 1,750 megawatts, initiating “Emergency Operations Level 2.” At 1:20 a.m., ERCOT entered “Emergency Operations Level 3.” The situation continued to deteriorate, and ERCOT was soon forced to take action to prevent a cascading collapse of its system. Rolling blackouts began with 10,800 megawatts of load dropped by 2:00 a.m.—about 15% of demand at that time (ERCOT, 2021).

According to the laws of physics, the instantaneous supply of electricity must exactly equal demand at all times in an electric grid. System operators roughly balance supply and demand by “dispatching” generation plants when aggregate customer demand rises or falls. Small imbalances in supply and demand are corrected by governors at generation plants—so called “Automatic Generation Control” (AGC).

During normal operations, the system frequency of electric grids in the United States is 60 cycles per second (60 hertz). Electric grids commonly experience “disturbances”—for example, when generation plants unexpectedly trip off. At the time of a disturbance, the system of generation, transmission, distribution, and load instantaneously adjusts supply and demand without dispatch or active control by temporarily reducing system frequency. As the system frequency falls, demand goes down because electric motors and other frequency dependent loads consume less electricity. AGC systems at thermal plants then supply more fuel to turbines and boilers to increase generation, increasing system frequency. In a similar process at hydroelectric plants, AGC systems increase water flow through turbines. If plants cannot promptly increase their generation, then protective devices in the grid will automatically shed load to regain system balance and return system frequency to 60 hertz—so-called “Under Frequency Load Shedding” (UFLS).

When system frequency drops below 60 hertz for more than a few minutes, this can cause vibrations, fatigue, and permanent failure of turbine blades in thermal generation plants. Accordingly, both ERCOT and the North American Electric Reliability Corporation (NERC)² have set UFLS frequency thresholds and time limits to preserve system stability and prevent equipment damage. In the ERCOT system, load is automatically shed when system frequency is below 59.4 hertz for 9 minutes or more (ERCOT, 2021).

The proximate cause of the load drop ordered by ERCOT was a rapid sequence of generation outages—6,078 megawatts in total between 1:20 a.m. and 2:03 a.m. Generation plants initially tripped off because of temperature-related malfunctions (ERCOT, 2021). However, as plants tripped off, the frequency of the ERCOT system rapidly declined, which may have induced other plants to trip off to protect their equipment—even before the 9-minute threshold for UFLS (Texas House of Representatives, 2021).

On February 15 at 1:51 a.m., ERCOT system frequency dropped below 59.4 hertz and stayed below that level for 4 minutes and 37 seconds. Had the frequency remained below this threshold for 9 minutes, UFLS would have been automatically imposed, potentially destabilizing the system and causing a cascading collapse

2 The North American Electric Reliability Corporation is the accredited standard-setting body for the high voltage portions of the U.S. and Canadian electric grids. NERC has been selected for this role by its federal regulator, FERC, and has been given authority to both set and enforce reliability standards.

throughout ERCOT. Even without UFLS, damage to generator turbines could have caused long-term plant outages. To maintain reserve margins and prevent additional frequency dips, ERCOT ordered preemptive load sheds at distribution utilities until Thursday, February 18 (ERCOT, 2021).

Figure 3 below shows ERCOT forecast demand versus generation resources available during the February load sheds. The black portion of the chart shows the timing and estimated amount of preemptive load sheds. When load is shed, it is impossible to precisely determine that amount of electricity that consumers would have used if load had not been shed. Therefore, the black part of the chart is the difference between *forecast demand* (based on temperature, time of day, day of week, and past patterns of electricity demand) and actual generation.

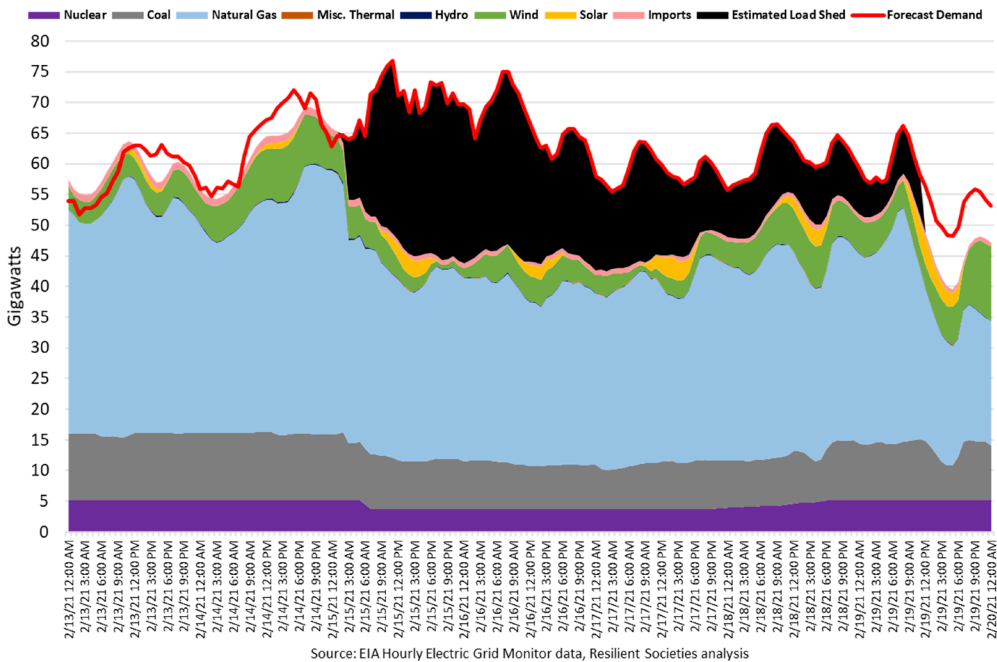


Figure 3. Demand vs. Resources during February 2021 Load Sheds in ERCOT

Figure 3 also shows the types of generation available from February 13 through February 19. Most nuclear reactors, represented in the purple portion of the chart, provided reliable baseload power throughout this period. However, Unit 1 at South Texas Project tripped off due to cold weather on February 15 and took several days to recover. Coal-fired plants, represented by the color gray, initially provided nearly constant baseload power until they began to trip off the morning of February 15. Natural gas-fired plants, represented by light blue, supplied the majority of load. Wind turbines, represented by green, provided significant amounts of non-dispatchable power before the load sheds, but less as they froze up during the week. Solar power, represented by yellow, contributed to load only during day-

light hours. Hydroelectric power and imports, represented by the colors dark blue and pink, respectively, contributed negligible amounts to load (EIA, 2021).

While aggressive load sheds avoided a total collapse of the ERCOT system during the early morning of February 15, significant outages continued throughout the day. At 10:11 p.m., 4,395,193 out of 12,448,564 customers were blacked out (PowerOutage.US, 2021). Blackouts were intended to be “rolling”—or rotating among affected customers—but distribution utilities also tried to keep feeders to critical infrastructure such as water purification plants and hospitals continuously energized. As a result, some customers were continuously blacked out for days while others had no interruption of power at all.

One of the most contentious events during this period took place the evening of Monday, February 15. The PUCT met in emergency session due to the concern that real time electricity prices were well below the HCAP level of \$9,000/megawatt-hour and that these prevailing prices were too low to incent generation to be available for dispatch. The PUCT approved an Order for PUC Project No. 51617, which consisted of two major provisions: (1) directed ERCOT to manually force the real time price to the HCAP level of \$9,000/megawatt-hour as long as load sheds were required; and (2) kept the HCAP in place even though the PNM threshold value was about to be reached, which should have triggered the LCAP (PUCT, 2021). While Provision 1 has received significant press coverage and achieved a national level of notoriety, Provision 2 has received scant attention. In brief, had the PUCT not taken action to avert the triggering of the LCAP, we calculate that an additional \$25 billion of cost would have been added to the bills of ERCOT customers due to the spike in natural gas prices.

By the morning of February 17, ERCOT had been able to restore power to a small fraction of the households affected, 1.6 million (ERCOT, 2021). On February 18, ERCOT Senior Director of System Operations Dan Woodfin said, “We’re to the point in the load restoration where we are allowing transmission owners to bring back any load they can related to this load shed event.” Remaining outages on this day were due to ice storm damage, the need for manual restoration with line crews, and closure of large industrial facilities that had gone offline voluntarily (ERCOT, 2021). As of 7:30 a.m. on February 19, 20,000 megawatts of thermal generation and 14,000 megawatts of wind and solar generation remained on forced outage (ERCOT, 2021). Later that same day, rising temperatures decreased customer demand, allowing all outages to be restored.

ERCOT narrowly avoided an alternative course of events, a disastrous long-term blackout. As CEO Magness testified in March before the U.S. House Energy and Commerce Committee, “Avoiding a complete blackout is critical. Were it to occur, the Texas grid could be down for several days or weeks while the damage to the electrical grid was repaired and the power restored in a phased and highly controlled process ... As terrible as the consequences of the controlled outages in

February were, if we had not stopped the blackout, power could have been out for over 90% of Texans for weeks” (Rev.com, 2021).

To recover from a complete blackout, electric utilities use small “blackstart” generators to re-energize larger power plants. Blackstart is difficult because increasing generation must be coordinated with lumpy additions to demand—a process that can cause protective devices in the grid to trip. Adding to this avoided challenge for ERCOT, later research by the *Wall Street Journal* revealed that nine of 13 primary blackstart generators were out of commission at times during the Storm Uri event and six of 15 secondary generators had periodic trouble (Smith, 2021).

Causes

Even while the ERCOT blackouts were still ongoing, robust disagreement about the causes emerged. Four operational causes were proposed early on: higher than expected customer demand due to the low temperatures, thermal plants freezing up, dependence on wind turbines that likewise froze up, and shortages of natural gas for plants relying on this fuel source.

Quantified analysis using EIA data found that electric generation plants of all types failed to perform during the February 2021 deep freeze of Winter Storm Uri. Figure 4 shows actual generation from four major generation types—natural gas, coal, nuclear, and wind—as a percent of specified generation in the ERCOT Seasonal Assessment of Resource Adequacy (SARA) for winter 2020-2021. During the period of rolling blackouts, as represented in the gray portion of the chart, all four generation types performed well below planned capacity.

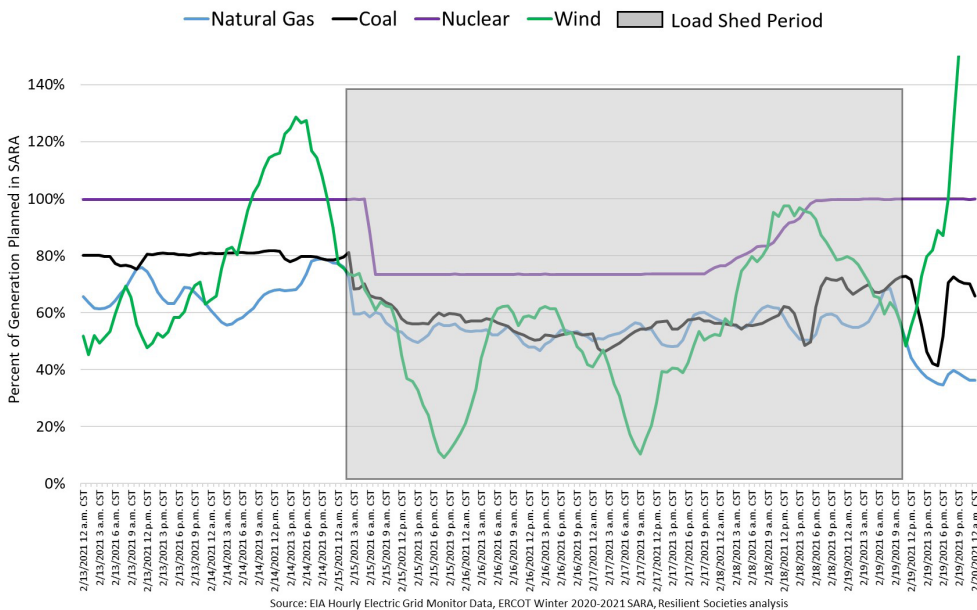


Figure 4. Actual ERCOT Generation in February 2021 as a Percent of Planned Capacity

Moreover, even if ERCOT’s generation plants had performed as planned, a blackout still would have occurred because electricity demand was far in excess of the upper bound in the SARA. Figure 5 shows demand at the previous winter peak on January 17, 2018; peak demand for the extreme weather scenario in the winter SARA; planned resources for winter 2020-2021; actual resources on February 15 at 11 a.m.; and estimated peak demand on February 15 at 11 a.m. At planned capacity, ERCOT would have been short nearly 10,000 megawatts at 11 a.m. and short at other times, too, over the course of the blackouts.

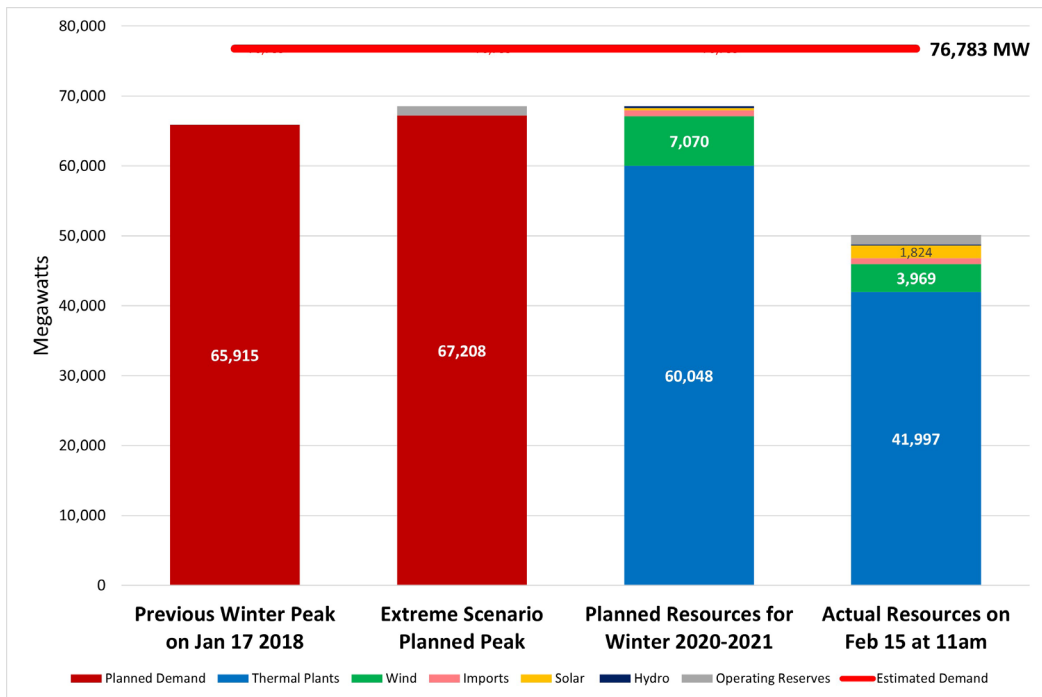


Figure 5. Estimated Peak Demand (76,783 MW) in ERCOT on February 15 at 11 a.m. vs. Resources

Figure 6 shows the megawatt contributions to load sheds on February 15 at 11 a.m. The No. 1 cause was forced outages at thermal plants (18,051 megawatts), followed by demand over the planned scenario (9,575 megawatts). Wind turbine deficits contributed a minor proportion (3,101 megawatts). At this time in the day, solar generation slightly over performed (1,520 megawatts). The contributions of hydroelectric holdbacks and import deficits were negligible (EIA, 2021).

The impact of rolling blackouts on natural gas supplies to generating plants during the February event was a topic of high interest during hearings in the Texas State Legislature. Anecdotally, there were reports of power to oil fields being diverted to hospitals and nursing homes. Because most natural gas production in Texas is “associated gas”—or gas that is obtained as a byproduct of pumping oil from the ground—when power to oil pumps was shut off, gas production stopped

as well. Additionally, some pipeline compressors in Texas are powered exclusively by electricity; when electricity to their feeders was shut off, this had the effect of reducing gas pressure and volume of delivered gas to generation plants (Adams-Heard, 2021).

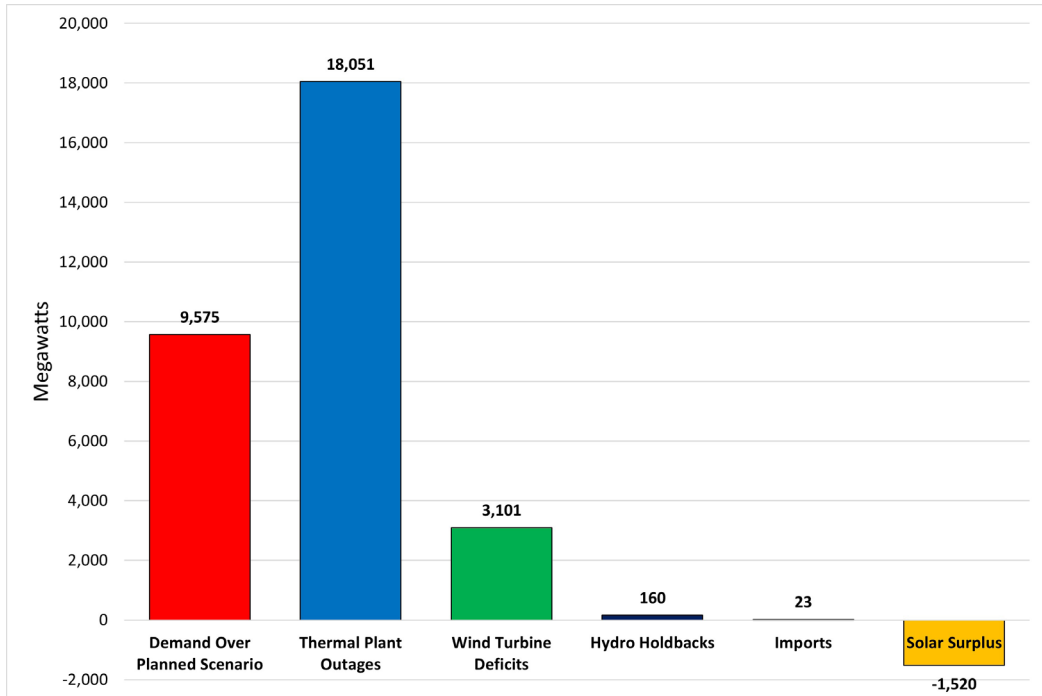


Figure 6. Peak Demand Contributions to Load Sheds in ERCOT on February 15 at 11 a.m.

On April 6, 2021, ERCOT submitted a “Preliminary Report on Causes of Generator Outages and Derates For Operating Days February 14 – 19, 2021 Extreme Cold Weather Event” to the PUCT. Legal restrictions prohibited release of information on individual plant outages, preventing detailed analysis by generation type. However, ERCOT did disclose the megawatts and proportions of generator outages and derates at their peak of 51,173 megawatts at 8:00am on February 16: Existing Outages of 7,487 megawatts (15%); Weather Related of 27,472 megawatts (54%); Fuel Limitations of 6,124 megawatts (12%); Equipment Issues of 6,986 megawatts (14%); Transmission Loss of 1,259 megawatts (2%); Frequency Related of 1,260 megawatts (2%); and Miscellaneous of 585 megawatts (1%) (ERCOT, 2021).

From the winter SARA, we know that natural gas fired generation had nameplate capacity of 52,091 megawatts (ERCOT, 2021). We can reasonably assume no fuel limitations at nuclear and coal-fired plants during the cold weather because they have large quantities of fuel stored on-site. We instead assume all fuel limitations were at gas-fired plants. This allows a calculation of the proportion of

gas-fired generation in outage because of fuel limitations: 6,124 megawatts/ 52,091 megawatts = 12%—a significant amount.

Consequences

The consequences of ERCOT’s rolling blackouts during Winter Storm Uri have been severe. They include higher costs for electricity ratepayers, bankruptcy-inducing charges to utilities, property damage at homes and businesses, and loss of life.

For the month of February 2020, wholesale electricity prices in the ERCOT real-time market averaged \$26 per megawatt-hour. For February 2021, wholesale electricity prices averaged \$1,783—an increase of 68 times (Potomac Research, 2021). For 87.5 hours during the week of February 14, wholesale prices were forced to the HCAP price cap of \$9,000 per megawatt-hour (Griddy, 2021). Some additional electricity charges will eventually flow through retailers to ratepayers, but significant losses will be incurred by generation and distribution utilities, too.

Exelon Corporation operates three large gas-fired plants within ERCOT—Colorado Bend II, Wolf Hollow II, and Handley. These plants experienced forced outages due to the cold weather and were unable to supply electricity as contracted. Exelon estimates impact to company income of between \$560 million and \$710 million (Exelon, 2021).

Brazos Electric Cooperative is the largest generation and transmission power cooperative in Texas, serving 1.5 million citizens. Before the events of February 15-19, Brazos was financially strong with “A” to “A+” credit ratings. Brazos refused to pass charges from ERCOT through to their distribution member cooperatives—charges that would have been ultimately paid by individual ratepayers. Brazos instead declared bankruptcy on March 1 (Brazos, 2021).

Griddy Energy was a company with a distinctive business model. Each month Griddy charged its customers a flat rate of \$9.99 plus an additional usage charge. The usage charge was calculated by multiplying the real-time wholesale rate of electricity times the kilowatt-hours consumed. The week before the blackouts, Griddy encouraged customers to switch to other electricity retailers but 24,000 customers remained. When the wholesale rate spiked to \$9,000 per megawatt-hour (\$9 per kilowatt-hour) the week of February 14, additional charges for the average Griddy customer were approximately \$1,200 each. Griddy declared bankruptcy on March 15. State Attorney General Ken Paxton and a class action law firm sued to protect Griddy customers from the excess charges. If these lawsuits are successful, unpaid invoices from ERCOT to Griddy will be allocated to other ERCOT retailers (Griddy, 2021; KXII Staff, 2021; Portello-Ronk, 2021; Chediak, 2021).

The total amount of generator, distributor, and retailer losses and excess ratepayer charges during the period of extreme electricity prices cannot be precisely determined from publicly available data, but a range can be estimated. For

ERCOT operating days February 15-21, the total amount of funds obligated to be paid to market participants was \$15.2 billion (Ogelman, 2021). However, in Texas a significant amount of electricity is traded in bilateral contracts between generators and distributors—trading that settles outside of the ERCOT market. To calculate a rough upper bound of utility losses and excess charges—including the bilateral trades—we multiplied the electricity consumed in ERCOT during the time of the load sheds (5,048 megawatt-hours) (U.S. Energy Information Administration, 2021) times the HCAP price cap (\$9,000 per megawatt-hour). The result was an upper bound figure of \$45.4 billion, which compares closely with another published estimate of \$47 billion (McWilliams, 2021). A midpoint estimate of utility losses and excess ratepayer charges taken together would be \$30 billion.

EIA data shows the vast majority of losses related to the electricity sector were initially taken by generators and retailers, not by consumers. In February 2020, sales of electricity to ultimate consumers totaled \$2.578 billion. For February 2021, this figure was \$3.951 billion—a moderate difference of \$1.373 billion month-to-month compared to total losses on the order of \$30 billion. We therefore estimate that losses initially taken by generators and retailers were approximately 95% of total losses related to the electricity sector. Consumer price increases were small; average prices for residential consumers in Texas rose only moderately from \$11.96 per megawatt hour in January 2021 to \$12.74 per megawatt hour in February 2021 (U.S. Energy Information Administration, 2021). Nonetheless, electricity retailers could try to recover some of their Storm Uri losses through future price increases to consumers, while generators might attempt to bid higher prices in the day-to-day wholesale electricity market.

Who principally gained from high electricity prices? Operators of reliable generation plants made large profits, per the intended design of the Energy Only market system. Suppliers of natural gas also profited from higher prices charged to generators. During the week of February 14, prices at OneOK Gas Transmission soared to \$1,250 per million BTU before returning to normal levels of \$3 per million BTU. During the same week, spot gas at the Houston Ship Channel hit \$400 per million BTU (Gonzales, 2021). As another indicator, revenues for Kinder Morgan, a large natural gas pipeline and storage operator in Texas, surged to \$5,211 million in the first quarter of 2021 from \$3,106 million in the prior-year quarter; adjusted earnings increased by \$907 million. Company executives attributed the better results to one-time gains from Winter Storm Uri (Kinder Morgan, 2021).

Other economic impacts of the Uri blackouts include loss of business and personal income, supply chain interruptions, and property damage when pipes froze. AccuWeather estimated \$130 billion of economic damages in Texas (Insurance Journal, 2021). The Perryman Group, an economic consulting firm, estimated damages between \$85.8 billion and \$128.7 billion (Perryman Group, 2021). Adding \$30 billion of utility losses and excess ratepayer charges to other economic

losses would result in an estimate for total economic losses between \$116 and \$159 billion.

In addition to economic losses, numerous lives were lost due to the cold weather and associated blackouts. On April 9, the Texas Department of State Health Services estimated 133 deaths between February 11 and March 5, with the majority due to hypothermia—a preventable cause of death when reliable electricity service is maintained (Texas Department of State Health Services, 2021).

Cures

Multiple cures have been proposed for the conditions that lead to the ERCOT blackouts during Winter Storm Uri. These include reliability standards that would require weatherization, a higher price cap for electricity prices, auction-based incentive payments for generators to maintain capacity (“capacity market”), payments to generators out-of-market to maintain capacity (typically called “Reliability Must Run” contracts), and a return to cost-of-service regulation. Some have suggested that Texas should integrate its grid with the electric grids of other states, a move that would place ERCOT under market and transmission tariff regulation of FERC.

Presently, federal regulation of the Texas grid is confined to the mandatory system of NERC reliability standards; FERC does not regulate the ERCOT market system. In their report on the 2011 Southwest Cold Weather Event, FERC and NERC staff confirmed that NERC and its regional delegate, the Texas Reliability Entity, have authority to set mandatory reliability standards for ERCOT, but did not recommend a standard be set for weatherization. At the time of the February 2021 blackouts, NERC had initiated a project for a weatherization standard, but this effort was years away from completion at the normal pace of standards development. Enforcement of NERC standards has been light-handed, with few monetary fines and administrative exceptions often granted. While FERC has legal authority to require more stringent standards and stronger enforcement, it has been cautious in exercising this authority.

When capacity shortfalls have occurred in ERCOT, the repeatedly imposed “solution” has been to raise the market price cap. To incent more generation capacity, ERCOT increased the HCAP market price cap five times between February 2011 and June 2015, starting at \$2,250 per megawatt hour and ending at \$9,000 per megawatt hour.

The February 2021 blackouts demonstrated that even \$9,000 per megawatt-hour is not enough to incent reliable generation or reduce consumer demand. Why? Because generators can recoup reliability investments only when prices spike very high; these rare events are likely to fall outside the tenure of most utility executives. These same executives are evaluated quarterly on other perfor-

mance metrics, such as profit and loss. Executive incentives are therefore skewed against long term investments such as weatherization. Moreover, no amount of financial or managerial incentive can cause new generation capacity to be constructed during an energy emergency. In regard to demand reduction incentives, high wholesale electricity prices are unlikely to cause most residential consumers to turn off their heat and risk burst pipes (or hypothermia), especially if the consumers are on rate plans that protect against price spikes. Some industrial users of electricity did voluntarily stop consuming, but this reduced demand was not enough to prevent blackouts for residential consumers.

On March 3, 2021, the PUCT reinstated the ERCOT price cap to the LCAP, which at the time was the higher of either \$2,000 per megawatt hour or 50 times the natural gas fuel index price at Katy, Texas. Since then, the PUCT has begun the process (through Project No. 51871) to reduce the natural gas multiplier from 50 to 25 to avoid “absurd results” in the future.

So-called “capacity markets” are an adjunct to the daily electricity markets operated in other RTOs/ISOs such as PJM, NYISO, and ISO-New England. Generator payments for installed capacity are auctioned, typically 1-3 years in advance of the performance period. Capacity payments can be quite large—for example, in New England capacity payments are approximately one-third of the total payments for wholesale power.

A fundamental issue with capacity markets is that the market rules are set by the market participants—including operators of generation plants—consistent with the industry-dominated governance systems of RTO/ISOs. Within the FERC review and approval process, opponents of RTO/ISO market rules have a high legal bar. Financial penalties are a key part of capacity market rules—i.e., the amount of money generators must return to the RTO/ISO if their contracted capacity is not available during a declared energy emergency. Such financial penalties can be a small fraction of overall payments to generators. Therefore, a viable business strategy for generators is to underinvest in reliability improvements and simply pay the penalty if the plant is in forced outage during an energy emergency. But if financial penalties were set higher, this could dissuade participants from entering the capacity market.

When market failures for reliable generation have occurred in RTO/ISO outside of Texas, out-of-market payments—so-called Reliability Must Run (RMR) contracts—have been a costly remedy. In recent years FERC has allowed RMR contracts for Southern California and the Boston area. More recently, Berkshire Hathaway Energy proposed the construction of ten new natural gas fired plants in ERCOT for \$8.3 billion. These plants would operate only during energy emergencies. The Berkshire plants would store natural gas on-site, alleviating the problems experienced with fuel supply during the February blackouts. Competing generation companies testified before the Texas State Legislature that this proposal would

be unfair because it would undercut previous decisions to invest in generation plants. Moreover, competitors said these emergency generators could cause day-to-day capacity in the Energy Only market to exit—ostensibly because existing generators could not look forward to recouping new investments in reliability during times of high prices.

A *Morning Consult* survey released on February 24 indicated that “56% of U.S. voters say Texas should connect its electric grid with those of other regions, while 24% said the state should continue its independent operation” (Morning Consult, 2021). Presumably, the interests of the vast majority of U.S. voters diverge from Texan interests—but constituents outside of Texas would indirectly have a say in the management of the State’s grid if it were to be integrated with the Eastern Interconnection and placed under federal regulation. Sentiment among Texas policymakers has been different. Former Texas Governor Rick Perry was quoted as saying, “Texans would be without electricity for longer than three days to keep the federal government out of their business.”

The potential federal regulator, FERC, has responsibilities that go far beyond regulation of electricity markets. FERC is also responsible for hydroelectric dam permits, pipeline approvals and their tariff regulation, liquified natural gas facilities, and grid reliability standards for the nation as a whole. Each year FERC processes thousands of orders, permits and rulemakings. The amount of attention that FERC could give to the problems of Texas would be constrained. Additionally, FERC rulings would necessarily balance the interests of Texas with those of other states.

A rationale for the integration of electric grids is greater resilience; presumably, a system encountering a disturbance or electricity shortage could rely on its neighbor’s resources. However, for wide-area events extending beyond the border of a balancing area, reserves in other systems may not be available. Potential wide area events include extremely hot and cold weather, natural gas pipeline interruptions, geomagnetic disturbance (also called “solar storms”), cyberattack, physical attack, electromagnetic attack, and propagating disturbances that result in grid islanding or cascading collapse.

Real-world experience shows that integration of the ERCOT system with neighboring interconnections may have marginal benefit while increasing risk. During the February 2021 events, neighboring electric grids experienced their own power deficits and some imposed rolling backouts. Furthermore, the magnitude of the ERCOT blackouts would have dwarfed reserves likely available in neighboring systems: even California ISO, the largest importer of electricity, imports at most 12 gigawatts while the deficit in ERCOT during February 2021 was over twice that amount. A disturbance in a neighboring electric grid can cause a wide-area cascading collapse—as happened in August 2003, when a transmission disturbance starting in Ohio propagated through Ontario and eight U.S. states. The resulting blackout affected 55 million people.

A potential cure for Texas' market ills would be a return to the "cost-of-service" regulatory system. Roughly one-third of the U.S. still operates under the cost-of-service regulatory model for electricity generation. Under this model, needed generation would be planned by utilities and renumeration would be approved by the PUCT. Most states in an RTO/ISO market system would have difficulty exiting, but Texas would have an easier pathway. Texas has its own electric grid with minimal imports and substantial in-state generation. Importantly, Texas has avoided market regulation by FERC and therefore could return to a cost-of-service model solely by action of its legislature.

By establishing a "deregulated" electricity market, regulators for Texas and other states had hoped to eliminate ratemaking cases and also lower electricity rates for consumers. The subjective nature of ratemaking cases under the cost-of-service model makes it difficult for regulators to enforce efficiencies in plant construction and operation. Under the cost-of-service model, cost overruns for ambitious (or unnecessary) generation projects can be placed upon electricity consumers.

However, recent experience demonstrates that a return to the cost-of-service system could be less expensive for Texas consumers—especially when the extraordinary charges of rare events are factored in. Shortly after the February blackouts, the *Wall Street Journal* published a study titled, "Texas Electric Bills Were \$28 Billion Higher Under Deregulation." By comparing rates for consumers in the cost-of-service portions of Texas to the rates in the ERCOT portion, the authors concluded that rates in the cost-of-service portion were 8% lower, on average. The authors also found that consumers in ERCOT paid \$28 billion more for their power from 2004 to 2020 than if they had paid rates charged to consumers in the cost-of-service portions of Texas during the same period. Studies by the Texas Coalition for Affordable Power, a government purchasing cooperative, came to similar findings (McGinty, 2021).

We analyzed electricity rate data provided by the EIA. These data show the total electricity rate by state for each year beginning in 1990. The total rate is a combination of the residential, commercial, industry and transportation categories tracked by the EIA (and "other" prior to 2003) (EIA, 2020). Below in Figure 7, we show the result of comparing the average annual electricity rates for Texas, New Mexico, and the U.S. average. New Mexico was selected for comparison for three reasons: (1) New Mexico has retained a cost-of-service electric system; (2) Texas and New Mexico share a long common border; and (3) the Permian basin straddles the common border. The fracking revolution in the Permian basin has been the defining event of the U.S. oil and gas industry in the 21st century and has had a profound influence on the cost of fuel used to generate electricity.

As shown in Figure 7, Texas electricity rates have varied wildly, peaking in 2008 before dropping to a fairly stable level in 2012. By comparison, rates in New

Mexico have risen relatively slowly. Although the rate increase from 1996, when ERCOT began operating the competitive market, to 2019 is less than the U.S. average, it is more than that experienced in New Mexico. And we already know that the 2021 rate for Texas will be significantly higher because of the Storm Uri event. The assertion by one prominent electricity market advocate that “Having straddled the divide between traditional cost-of-service regulation and modern market-based competition, I can assure you the competitive model is the better way to bring price, service and technological innovation benefits to customers” is not consistent with these data (Wood, 2021).

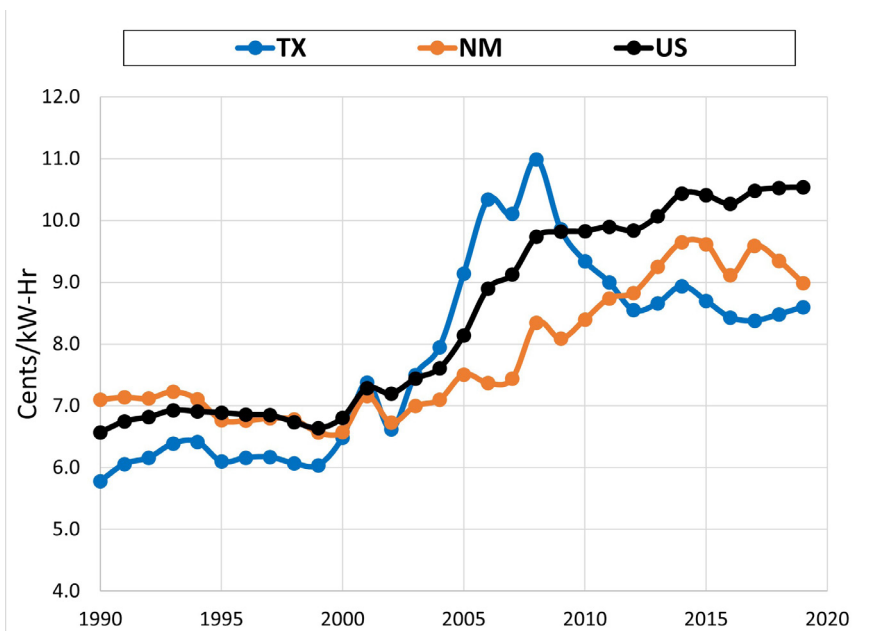


Figure 7. Comparison of Average Electricity Rates in Texas, New Mexico, and the U.S. Average

Other than lower costs to ratepayers, the advantages of the cost-of-service model could be substantial. The types and capacities of generation can be selected for their cost, reliability, and carbon emissions. There is a direct pathway between planned capacity and constructed capacity. Most importantly, if a blackout occurs, the responsible parties can be easily identified and held accountable—and this alone could make blackouts less likely.

Conclusions

For 25 years, Texas has operated the Wild West of electricity markets. During Winter Storm Uri in February 2021, financial losses and human casualties resulted. Repeated increases in the market price cap did not incent sufficient reliable generation but did result in large losses to the electricity sector. Losses also

resulted for a small proportion of unfortunate consumers whose rates were tied to wholesale prices, i.e., “Griddy” customers. No financial incentive can increase generation capacity when a blackout is already underway. A total collapse of the ERCOT system was narrowly avoided—not by market forces, but by direct action of grid operators.

Most elaborations of ERCOT’s Energy Only electricity market have potential defects. In an Energy Only market, generators have no ready means to recover the cost of reliability improvements and therefore are likely to resist weatherization—whether reliability standards require this or not. Capacity markets provide large payments to market participants without assurance that capacity will be available in an emergency. RMR contracts are expensive and temporary solutions that can also distort day-to-day electricity markets. Integration with neighboring electric grids does not provide sure benefits during wide-area events that also affect neighboring electric grids. In addition to a shared shortage of capacity during extreme weather and other wide-area energy emergencies, integration could also increase susceptibility to cascading collapses.

Because Texas has an independent electric grid that is not regulated by FERC, this State is well-situated for a return to the cost-of-service regulatory model. Under the cost-of-service model, the State could make direct decisions for its generation strategy—including types of generation and their capacities. With direct decisions come accountability. The cost-of-service model could reduce the probability of future blackouts while avoiding the egregious financial losses and human casualties experienced under the current market-based system.

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Acronyms and Abbreviations

AGC	Automatic Generation Control
BTU	British Thermal Unit
DC	Direct Current
EIA	U.S. Energy Information Administration
ERCOT	Electric Reliability Council of Texas
HVDC	High Voltage Direct Current

FERC	Federal Energy Regulatory Commission
HCAP	High system wide offer cap
ISO	Independent System Operator
LCAP	Low system wide offer cap
NERC	North American Electric Reliability Corporation
PNM	Peaker Net Margin
PUCT	Public Utility Commission of Texas
RMR	Reliability Must Run
RTO	Regional Transmission Organization
RUT	Railroad Commission of Texas
SARA	Seasonal Assessment of Resource Adequacy
UFLS	Under Frequency Load Shedding

Author Capsule Bios

Thomas S. Popik is Chairman and President of the Foundation for Resilient Societies, a nonprofit dedicated to the protection of critical infrastructure from infrequently occurring disasters. He specializes in the regulation of electric grids for reliability under both the cost-of-service and market-based models. He has testified on electric grid reliability before the Federal Energy Regulatory Commission, the Canadian Parliament, and the legislatures of multiple U.S. states and has been quoted in the *Wall Street Journal*, *Politico*, *The Economist*, *Reuters*, and *USA Today*. Mr. Popik holds a Master of Business Administration from Harvard Business School and a Bachelor of Science in Mechanical Engineering from MIT. In his early career, Mr. Popik served as an officer in the U.S. Air Force, with a final rank of Captain.

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References

Adams-Heard, Rachel; Blas, Jarier; and Chediak, Mark. (2021, February). "A Giant Flaw in Texas Blackouts: It Cut Power to Gas Supplies." Retrieved from [www.bloomberg.com](https://www.bloomberg.com/news/articles/2021-02-20/a-giant-flaw-in-texas-blackouts-it-cut-power-to-gas-supplies): <https://www.bloomberg.com/news/articles/2021-02-20/a-giant-flaw-in-texas-blackouts-it-cut-power-to-gas-supplies>

Blunt, Katherine and Gold, Russell. (2021, February). The Texas Freeze: Why the Power Grid Failed. Retrieved from [www.wsj.com](https://www.wsj.com/articles/texas-freeze-power-grid-failure-electricity-market-incentives-11613777856): <https://www.wsj.com/articles/texas-freeze-power-grid-failure-electricity-market-incentives-11613777856>

Blunt, Katherine and Gold, Russell. (2021, February). Amid Blackouts, Texas Scrapped Its Power Market and Raised Prices. It Didn't Work.. Retrieved from [www.wsj.com](https://www.wsj.com/articles/texas-power-regulators-decision-to-raise-prices-in-freeze-generates-criticism-11614268158): <https://www.wsj.com/articles/texas-power-regulators-decision-to-raise-prices-in-freeze-generates-criticism-11614268158>

Brazos Electric Cooperative. (2021, March 1). Brazos Electric Power Cooperative, Inc. Files for Chapter 11 Financial Restructuring. Retrieved from [www.brazoselectric.com](http://www.brazoselectric.com/pressrelease.pdf): <http://www.brazoselectric.com/pressrelease.pdf>

Chediak, Mark et. al. (2021, February 26). Ercot Still Short \$1.3 Billion in Energy Payments: Texas Update. Retrieved from [www.bloomberg.com](https://www.bloomberg.com/news/articles/2021-02-26/bankruptcies-loom-from-enormous-obligations-texas-update): <https://www.bloomberg.com/news/articles/2021-02-26/bankruptcies-loom-from-enormous-obligations-texas-update>

Coy, Peter. (2021, February). Ercot's 711-Page Training Manual Tells a Power-Grid Horror Story. Retrieved from [www.bloomberg.com](https://www.bloomberg.com/news/articles/2021-02-22/ercot-s-711-page-training-manual-tells-a-power-grid-horror-story): <https://www.bloomberg.com/news/articles/2021-02-22/ercot-s-711-page-training-manual-tells-a-power-grid-horror-story>

Electric Reliability Council of Texas. (2020, May). Final Seasonal Assessment of Resource Adequacy for the ERCOT Region (SARA) June-September 2020 Retrieved from [www.ercot.com](http://www.ercot.com/content/wcm/lists/197378/SARA-FinalSummer2020.xlsx): <http://www.ercot.com/content/wcm/lists/197378/SARA-FinalSummer2020.xlsx>

Electric Reliability Council of Texas. (2020, May). Report on Capacity, Demand and Reserves (CDR) in the ERCOT Region, 2021-2020. Retrieved from [www.ercot.com](http://www.ercot.com/content/wcm/lists/197378/SARA-FinalSummer2020.xlsx)

ercot.com: http://www.ercot.com/cotent/wcm/lists/197379/CapacityDemandandReserveReport_May2020.xlsx

Electric Reliability Council of Texas. (2020, November). Final Seasonal Assessment of Resource Adequacy for the ERCOT Region (SARA) Winter 2020/2021 Retrieved from www.ercot.com: <http://www.ercot.com/content/wcm/lists/197378/SARA-FinalWinter2020-2021.pdf>

Electric Reliability Council of Texas. (2021, February 11). Extreme cold weather expected to result in record electric use in ERCOT region. Retrieved from ercot.com: <http://www.ercot.com/news/releases/show/224996>

Electric Reliability Council of Texas. (2021, February 14). Grid operator requests energy conservation for system reliability. Retrieved from ercot.com: <http://www.ercot.com/news/releases/show/225151>

Electric Reliability Council of Texas. (2021, February 17). Grid operator continues to restore power. Retrieved from ercot.com: <http://www.ercot.com/news/releases/show/225696>

Electric Reliability Council of Texas. (2021, February 18). Majority of customers are able to be restored, but electric companies still restoring outages in the field. Retrieved from ercot.com: <http://www.ercot.com/news/releases/show/225742>

Electric Reliability Council of Texas. (2018, April 4). Inertia: Basic Concepts and Impacts on the ERCOT Grid. Retrieved from ercot.com: http://www.ercot.com/content/wcm/lists/144927/Inertia_Basic_Concepts_Impacts_On_ERCOT_v0.pdf

Electric Reliability Council of Texas. (2021, April 6). Preliminary Report on Causes of Generator Outages and Derates For Operating Days February 14 – 19, 2021 Extreme Cold Weather Event. Retrieved from ercot.com: http://www.ercot.com/content/wcm/lists/226521/51878_ERCOT_Letter_re_Preliminary_Report_on_Outage_Causes.pdf

Exelon Corporation. (2021, February 24). Exelon Reports Fourth Quarter and Full Year 2020 Results And Initiates 2021 Financial Outlook. Retrieved from www.exeloncorp.com: <https://www.exeloncorp.com/newsroom/Exelon-Reports-Fourth-Quarter-and-Full-Year-2020-Results>

Federal Energy Regulatory Commission and North American Electric Reliability Corporation. (2011, August). Report on Outages and Curtailments During the

Southwest Cold Weather Event of February 1 – 5, 2011. Retrived from www.ferc.gov: <https://www.ferc.gov/sites/default/files/2020-04/08-16-11-report.pdf>

Gonzales, Leticia. (2021, February 19). Historic Freeze Fuels Monstrous Weekly Natural Gas Price Rally, Leaves Texas Out in the Cold. Retrieved from www.naturalgasintel.com:<https://www.naturalgasintel.com/historic-freeze-fuels-monstrous-natural-gas-price-rally-leaves-texas-left-out-in-cold/>

Griddy Energy, LLC. (2021, March 15). To Former Customers of Griddy Energy: Notice of Bankruptcy Filing. Retrieved from www.griddy.com: <https://www.griddy.com/>

Insurance Journal. (2021, March 5). AccuWeather Raises Texas Damage, Loss Estimate from Winter Storm to \$130B. Retrieved from www.insurancejournal.com: <https://www.insurancejournal.com/news/southcentral/2021/03/05/604122.htm>

Jenkins, Lisa. (2021, February 24). Following Mass Power Failures in Texas, Over Half of Voters Say State Needs to Connect Its Grid to Others. Retrieved from <https://morningconsult.com>: <https://morningconsult.com/2021/02/24/texas-power-grid-independence-polling/>

Kinder Morgan. (2021, April 21). Kinder Morgan's First Quarter 2021 Earnings Results. Retrieved from ir.kindermorgan.com: <https://ir.kindermorgan.com/events-and-presentations/event-details/2021/Kinder-Morgans-First-Quarter-2021-Earnings-Results/default.aspx>

KXII Staff. (2021, March 16). AG Paxton Ensures Forgiveness of \$29 Million in Electric Bills for 24,000 Texans After Suing Griddy Energy, LLC. Retrieved from www.kxii.com: <https://www.kxii.com/2021/03/16/ag-paxton-ensures-forgiveness-of-29-million-in-electric-bills-for-24000-texans-after-suing-griddy-energy-llc/>

Magness, Bill. (2021, March 4). Texas Legislative Hearings:Senate Business and Commerce CommitteeHouse Joint Committee on State Affairs and Energy Resources. Retrieved from www.ercot.com: http://www.ercot.org/content/wcm/lists/226521/Texas_Legislature_Hearings_2-25-2021.pdf

Magness, Bill. (2021, February 24). Review of February 2021 Extreme Cold Weather Event –ERCOT Presentation. Retrieved from www.ercot.com: http://www.ercot.com/content/wcm/key_documents_lists/225373/2.2_REVISIED_ERCOT_Presentation.pdf

Magness, Bill. (2021, February 25). Texas Legislative Hearings:Senate Business and

Commerce Committee House Joint Committee on State Affairs and Energy Resources. Retrieved from www.ercot.com: http://www.ercot.com/content/wcm/lists/226521/Texas_Legislature_Hearings_2-25-2021.pdf

Malik, Naureen and Chediak, Mark. (2021, February). Texas Power Grid Chair, Directors Quit in Wake of Blackouts. Retrieved from www.bloomberg.com: <https://www.bloomberg.com/news/articles/2021-02-23/ercot-chair-vice-chair-and-others-resign-from-board-filing>

McGinty, Tom and Patterson, Scott. (2021, February 24). “Texas Electric Bills Were \$28 Billion Higher Under Deregulation.” Retrieved from www.wsj.com: <https://www.wsj.com/articles/texas-electric-bills-were-28-billion-higher-under-deregulation-11614162780>

McWilliams, Gary. (2021, March 5). Texas power regulator rejects request to cut \$16 billion in charges during freeze. Retrieved from www.reuters.com: <https://www.reuters.com/article/us-usa-texas-power-crisis-idUSKBN2AX2MA>

Ogelman, Kenan. (2021, March 4). ERCOT Market Update Texas Senate Business and Commerce Committee. Retrieved from www.ercot.com: http://www.ercot.org/content/wcm/lists/226521/Senate_Business___Commerce_Committee_030421.pdf

Perryman Group. (2021, February). Preliminary Estimates of Economic Costs of the February 2021 Texas Winter Storm. Retrieved from www.perrymangroup.com: <https://www.perrymangroup.com/media/uploads/brief/perryman-preliminary-estimates-of-economic-costs-of-the-february-2021-texas-winter-storm-02-25-21.pdf>

Portillo Ronk Legal Team. (2021, March 16). Information for Creditors of Griddy Energy LLC. Retrieved from www.portilloronk.com: <https://www.portilloronk.com/griddy-energy>

Potomac Economics, Ltd. (2021, March 10). ERCOT Wholesale Electricity Market Monthly Report. Retrieved from www.potomaceconomics.com: https://www.potomaceconomics.com/wp-content/uploads/2021/03/Nodal_Monthly_Report_2021-02.pdf

PowerOutage.us. (2021, February 15). Major Power Outage Events. Retrieved from <https://poweroutage.us>: <https://poweroutage.us/about/majorevents>

Public Utility Commission of Texas, “Second Order Directing ERCOT to Take

Action and Granting Exception to Commission Rules,” <https://www.puc.texas.gov/51617WinterERCOTOrder.pdf>

Railroad Commission of Texas. (1973, January). Order Relating To The Approval By The Commission Of Curtailment Programs For Natural Gas Transported And Sold Within The State Of Texas. Retrieved from rrc.texas.gov: <https://rrc.texas.gov/gas-services/curtailment-plan/>

Railroad Commission of Texas. (2021, February 12). RAILROAD COMMISSION OF TEXAS EMERGENCY ORDER. Retrieved from rrc.texas.gov: <https://rrc.texas.gov/media/cw3ewubr/emergency-order-021221-final-signed.pdf>

Rev.com. (2021, March 24). House Hearing on Texas Power Grid Failure Transcript March 24. Retrieved from www.rev.com: <https://www.rev.com/blog/transcripts/house-hearing-on-texas-power-grid-failure-transcript-march-24>

Texas House of Representatives. (2021, February 25). Joint Hearing: State Affairs and Energy Resources, Part 1. Retrieved from www.house.texas.gov: <https://www.house.texas.gov/video-audio/committee-broadcasts/>

S&P Global Market Intelligence. (2021, February). Experts mull market, reliability rule changes amid Texas, regional outages. Retrieved from www.spglobal.com: <https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/experts-mull-market-reliability-rule-changes-amid-texas-regional-outages-62688009>

Schneider, Jesse and Goggin, Michael. (2020, March 23). ERCOT 2019: Market Performance Assessment. Retrieved from <https://gridstrategiesllc.com>: <https://gridstrategiesllc.com/2019/10/14/ercot-2019-market-performance-assessment/>

Smith, Rebecca. (2021, May 27). The Texas Grid Came Close to an Even Bigger Disaster During February Freeze. Retrieved from www.wsj.com: <https://www.wsj.com/articles/texas-electrical-grid-bigger-disaster-february-freeze-black-starts-11622124896>

Sullivan, Brian. (2021, February 25). Most of Texas Deep Freeze \$90 Billion in Losses Avoidable, Modeler Says. Retrieved from www.insurancejournal.com: <https://www.insurancejournal.com/news/southcentral/2021/02/25/602807.htm>

The Texas Tribune. (2021, February). Texas was “seconds and minutes” away from catastrophic months-long blackouts, officials say. Retrieved from www.texastribune.org: <https://www.texastribune.org/2021/02/18/texas-power-outages-ercot/>

TimeAndDate.com. (2021, February). Past Weather in Austin, Texas, USA—February 2021. Retrieved from TimeAndDate.com: <https://www.timeanddate.com/weather/usa/austin/historic?month=2&year=2021>

Texas Department of State Health Services. (2021, April 9). Winter Storm-Related Deaths – April 9, 2021. Retrieved from dshs.texas.gov: <https://dshs.texas.gov/news/updates.shtm>

U.S. Energy Information Administration. (2021, February). Hourly Electric Grid Monitor. Retrieved from www.eia.gov: https://www.eia.gov/beta/electricity/grid-monitor/dashboard/electric_overview/balancing_authority/ERCO

U.S. Energy Information Administration. (2020, September). Form EIA-860 detailed data with previous form data (EIA-860A/860B). Retrieved from www.eia.gov: <https://www.eia.gov/electricity/data/eia860/>

U.S. Energy Information Administration. (2021, April). Electric Power Monthly. Retrieved from www.eia.gov: <https://www.eia.gov/electricity/monthly/>

U.S. Energy Information Administration. (2020, October). Electric Sales, Revenue, and Average Price. Retrieved from www.eia.gov: https://www.eia.gov/electricity/sales_revenue_price

U.S. Senate Committee on Energy and Natural Resources. (2021, March). Full Committee Hearing On The Reliability, Resiliency, And Affordability Of Electric Service. Retrieved from www.energy.senate.gov: <https://www.energy.senate.gov/hearings/2021/3/full-committee-hearing-on-the-reliability-resiliency-and-affordability-of-electric-service>

Wood, Pat. (2021, March 11). Testimony of Pat Wood, III CEO, Hunt Energy Network Before the United States Senate Committee on Energy and Natural Resources March 11, 2021. Retrieved from www.energy.senate.gov: <https://www.energy.senate.gov/services/files/371DBE67-1000-41FA-8E76-B467101AABE6>