Texas (ERCOT) Blackouts
What Happened? What's Next?

Paul L. Joskow

MIT

April 8, 2021

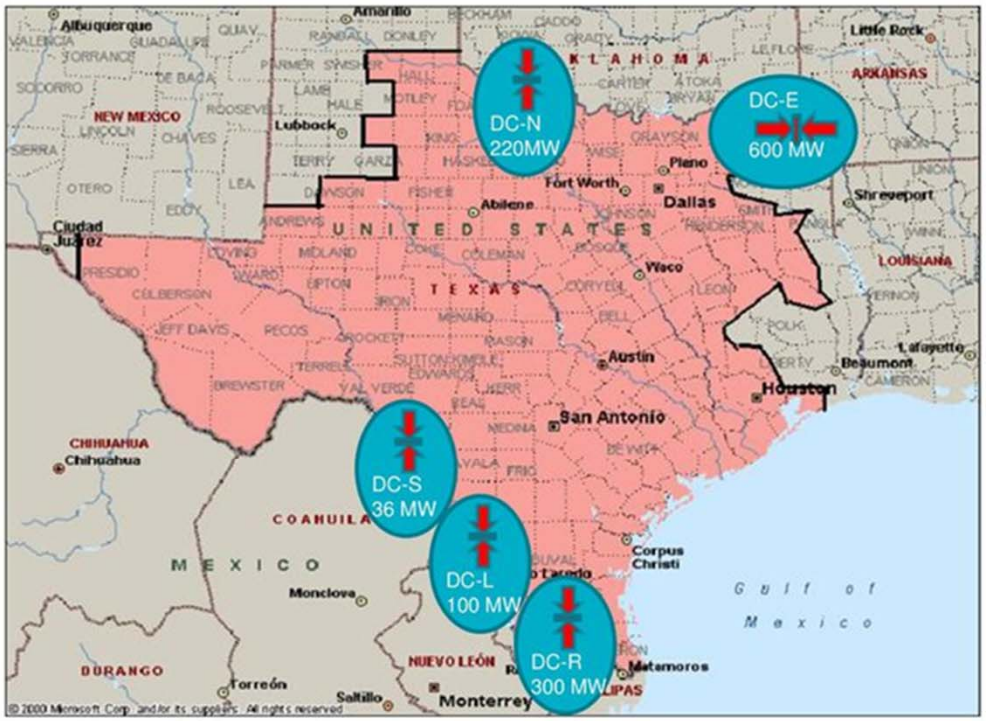
Outline

- Background on ERCOT
- What happened?
- What's next?

Source: SPP 2021

Current ERCOT DC Ties overview

- ERCOT - SPP (North, East)
- ERCOT - Mexico (CENACE) (South, Laredo, Railroad)



ercot

ERCOT
DC-TIE OPERATIONS

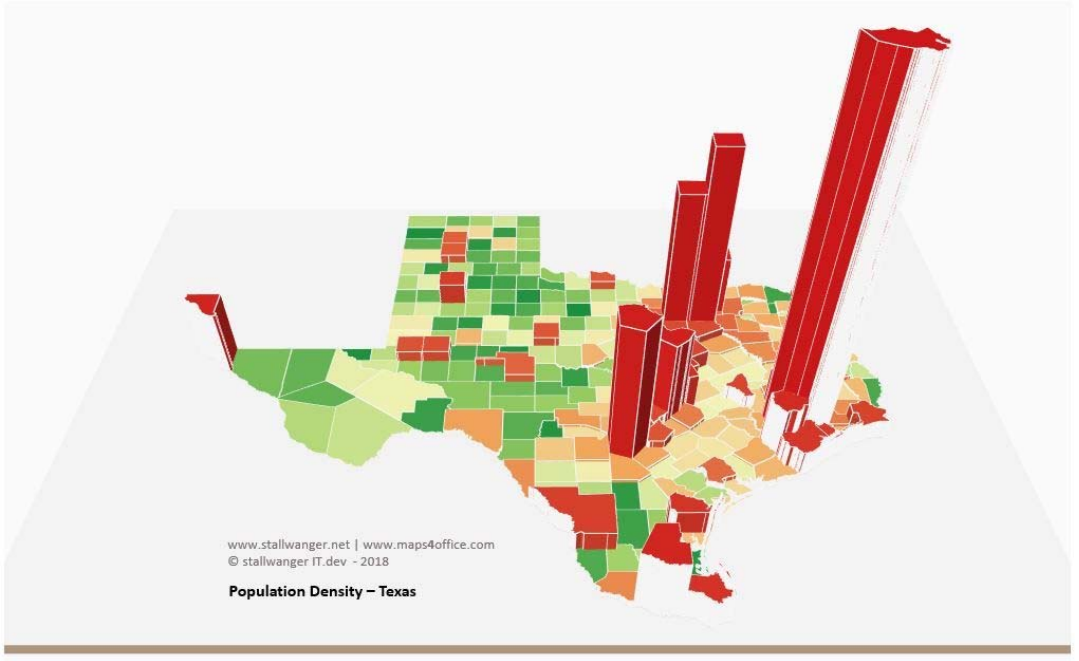
NERC Tagging, Interchange Scheduling, Normal and Emergency Operations, and Inadvertent Energy Accounting

Version 3.0 Rev 8
March 4, 2014

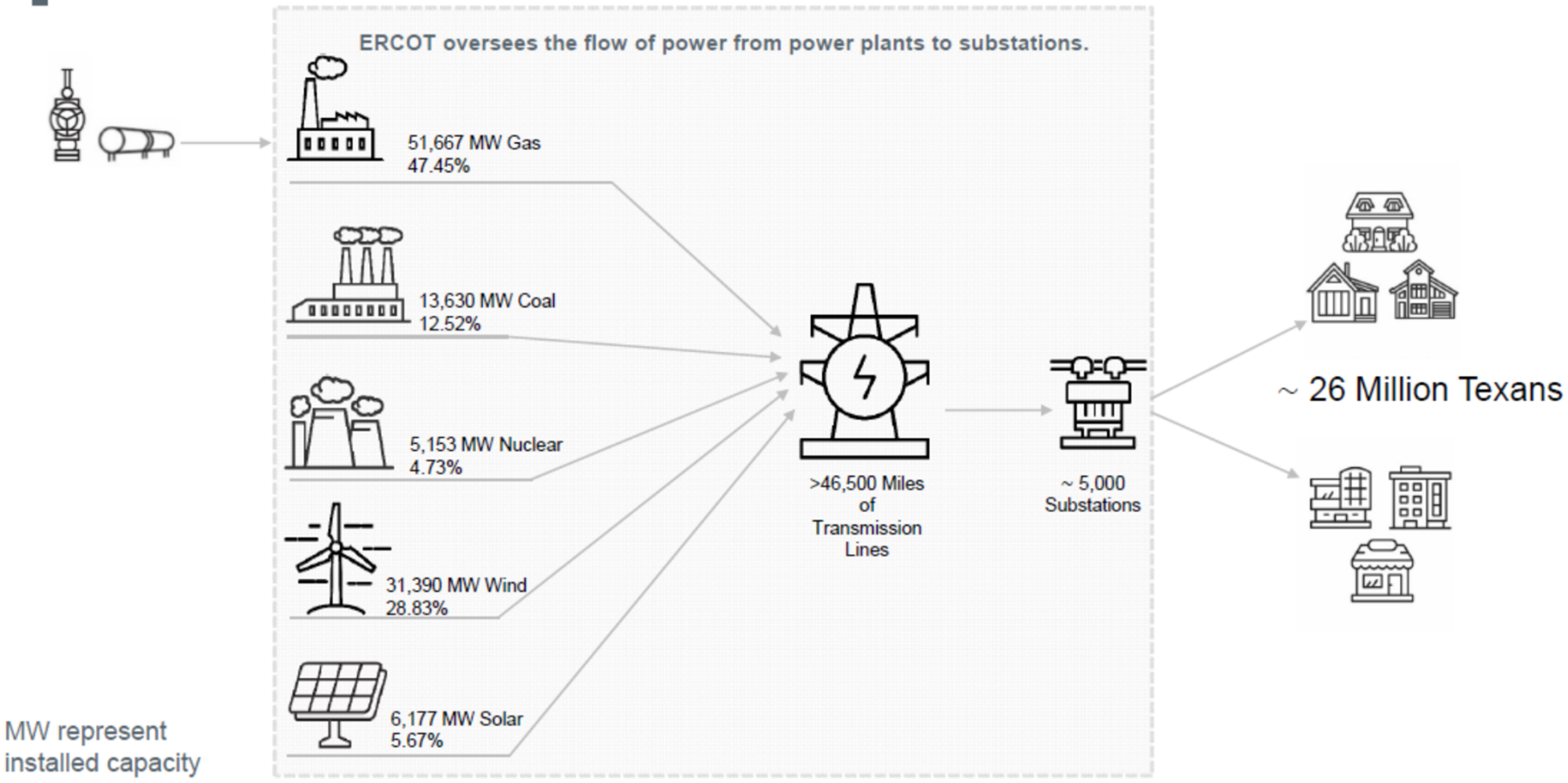
DC Tie	Operator
North	AEP
East	AEP
South	AEP
Laredo	AEP
Railroad	Sharyland

Summer peaking ~ 75,000 MW


Amarillo
Lubbock
Red River
Guadalupe
Mts. Nat'l Park
Midland
Fort Worth
Dallas
El Paso
Odessa
TEXAS
Waco
Rio Grande
Austin
Houston
San Antonio
Galveston
Big Bend
National
Park
Rio Grande
Laredo
Corpus Christi
Gulf of
Mexico
TourTexas.com
© 2005
S. Padre
Brownsville


www.stallwanger.net | www.maps4office.com
© stallwanger IT.dev - 2018
Population Density – Texas

Electric Generation, Transmission & Distribution Overview



ERCOT

- 1,800+ active market participants that generate, move, buy, sell or use wholesale electricity
- 86,000+ megawatts (MW) of expected capacity for summer 2021 peak demand
- 710+ generating units, excluding PUNs
- Transmission projects endorsed in 2020 total $1,071 million
- 46,500+ miles of high-voltage transmission

- Wind Generation record: 22,893 MW (Jan. 14, 2021)
- Wind Penetration record: 60.4 percent (Jan. 30, 2021)
- 25,121 MW of installed wind capacity as of Jan. 2021, the most of any state in the nation
- 3,854 MW of utility-scale installed solar capacity as of Jan. 2021
- 225 MW of installed battery storage as of Jan. 2021

74,820 MW
Record peak demand (Aug. 12, 2019)

73,821 MW
Weekend peak demand record (Aug. 15, 2020)

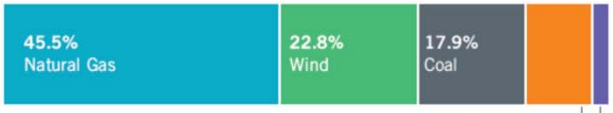
1 MW of electricity can power about 200 Texas homes during periods of peak demand.

2021 Generating Capacity

Reflects operational installed capacity based on the December 2020 CDR report

**Other includes hydro, biomass-fired units and DC tie capacity*

2020 Energy Use



**Other includes solar, hydro, petroleum coke, biomass, landfill gas, distillate fuel oil, net DC-tie and Block Load Transfer imports/exports and an adjustment for wholesale storage load*

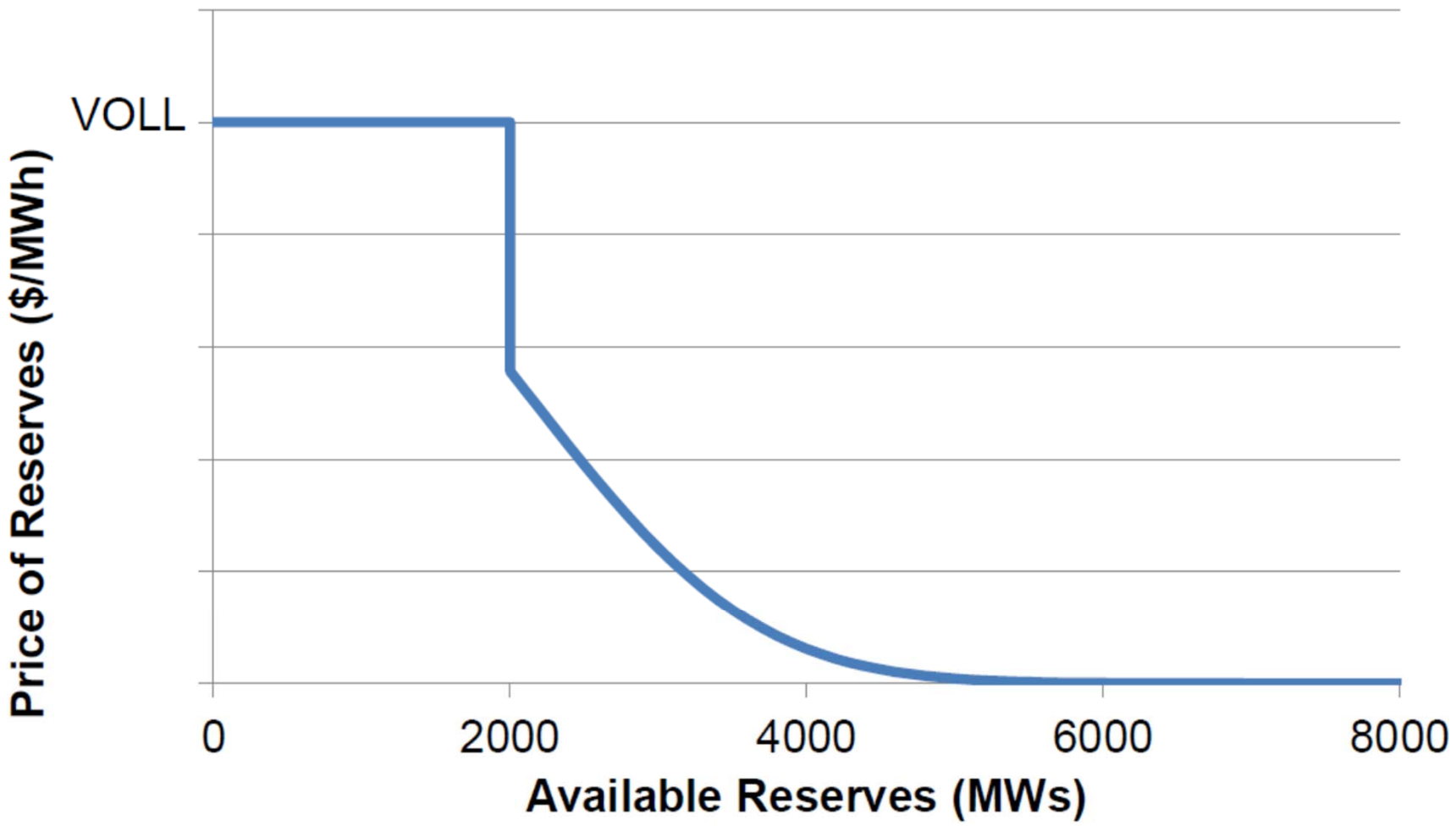
381 billion kilowatt-hours of energy were used in 2020, a 0.5 percent decrease compared to 2019.

Source: ERCOT

Institutional Framework in Texas

- ERCOT is an ISO with an independent board regulated by the TPUC (~ 90% of Texas)
  - Manages day-ahead and real time markets for energy and ancillary services
  - Standard short-term market design (LMP)
  - Transmission planning
  - Reliability assessments
  - Very limited interconnections with other supply areas
    - Limit Federal regulatory authority
- Resource Adequacy Obligations
  - In other areas capacity/reserve margin obligations are either assigned to LSEs or to the ISO which develops an installed capacity requirement (ICR) and uses a capacity market allocate and price commitments
  - ERCOT has no capacity obligations or capacity market as in other area
  - Relies instead on "scarcity pricing" in the energy market during tight supply situations
    - Generators, retail suppliers and financial firms can make forward commitments and hedge
  - Sets administrative Operating Reserve Demand Curve (ORDC) to determine price adders during tight supply situation
    - $9,000/ MWh price cap (VoLL?)
  - Analysis underlying ORDC
    - Similar to the analytics underlying resource adequacy calculations in other areas
    - Integrates intermittency attributes of wind/solar (mostly wind to date)
    - "check-in" with more conventional reserve margin analysis
- Retail supply competition
  - Virtually universal (except some municipal and cooperative utilities, e.g. City of Austin)
- Aggressive Decarbonization policy: No
- Texas Public Utility Commission (TPUC)
  - Regulates wholesale market design, distribution and transmission companies
  - Manages retail supply competition framework
  - Laissez Fair ideology

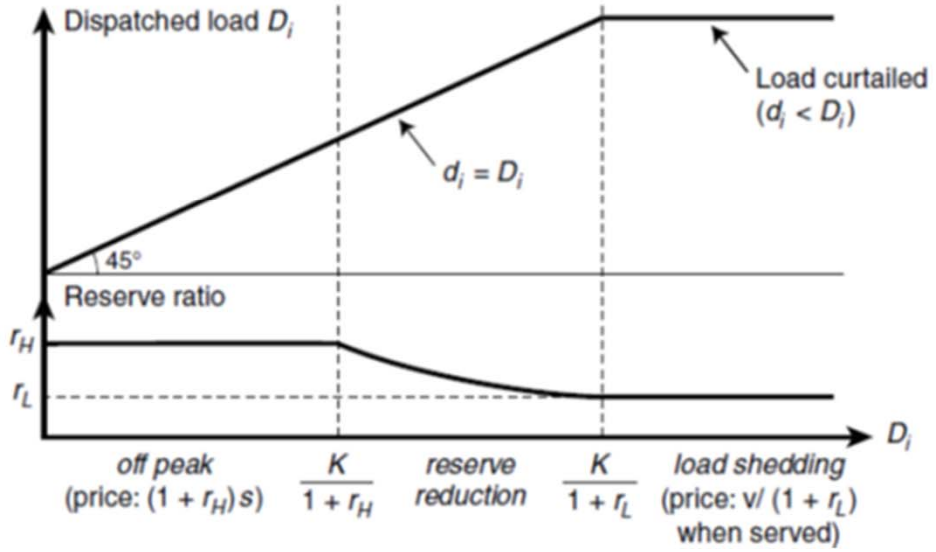
The Operating Reserve Demand Curve (ORDC)



ERCOT website

FIGURE 3

RAMSEY OPTIMUM (PRICES PAID BY CONSUMERS IN PARENTHESES)



Joskow and Tirole, RAND Journal of Economics (2007)

Real-Time LMPs for Load Zones and Trading Hubs Display

Help?

*LMP values **do not include** the Real-Time price adders.*

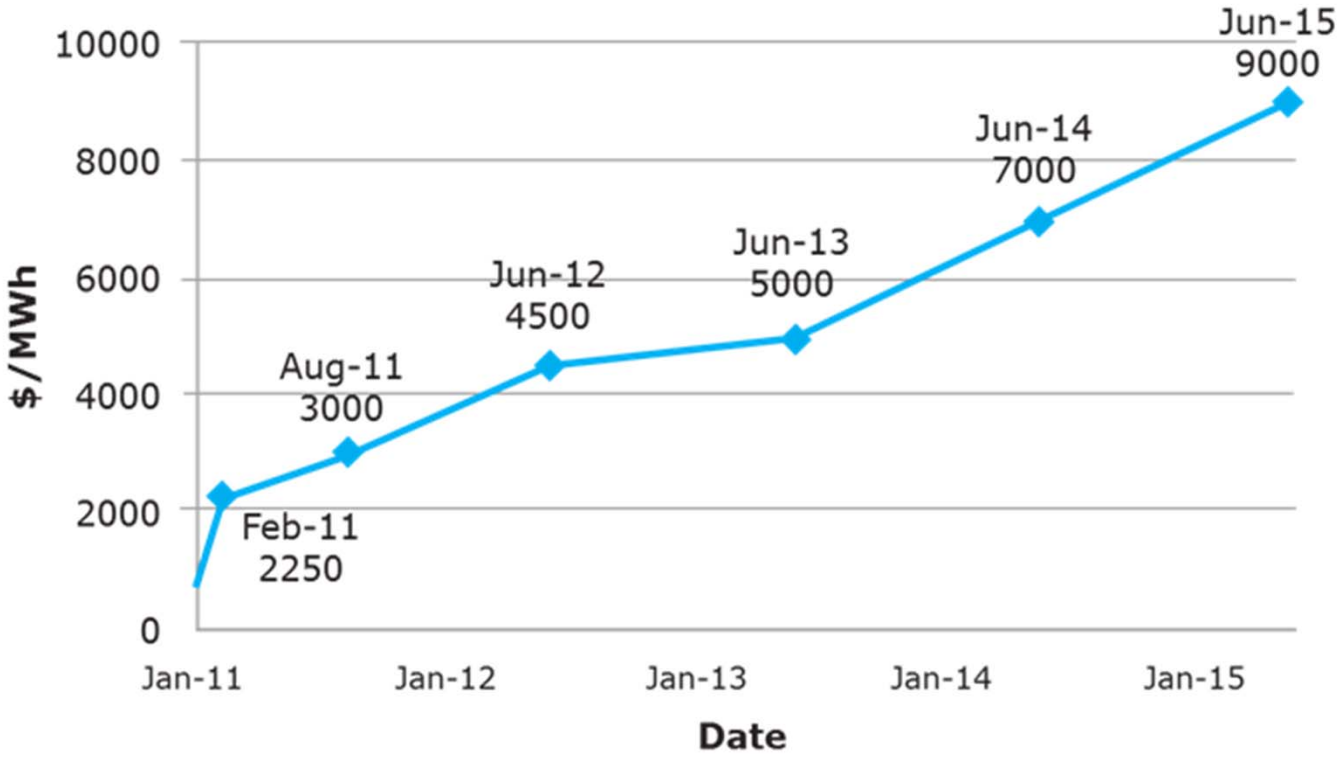
Last Updated: Feb 16, 2021 15:30:15

Price Adders RTORPA: $244.12 | RTOFFPA: $228.18 | RTORDPA: $7339.71 |

Settlement Point	LMP	5 Min Change to LMP	RTORPA + RTORDPA + LMP	5 Min Change to RTORPA + RTORDPA + LMP
HB_BUSAVG	1416.18	-54.11	9,000.01	0.01
HB_HOUSTON	1416.18	-54.11	9,000.01	0.01
HB_HUBAVG	1416.18	-54.11	9,000.01	0.01
HB_NORTH	1416.18	-54.11	9,000.01	0.01
HB_PAN	1416.18	-54.11	9,000.01	0.01
HB_SOUTH	1416.18	-54.11	9,000.01	0.01
HB_WEST	1416.18	-54.11	9,000.01	0.01
LZ_AEN	1416.18	-54.11	9,000.01	0.01
LZ_CPS	1416.18	-54.11	9,000.01	0.01
LZ_HOUSTON	1416.18	-54.11	9,000.01	0.01
LZ_LCRA	1416.18	-54.11	9,000.01	0.01
LZ_NORTH	1416.18	-54.11	9,000.01	0.01
LZ_RAYBN	1416.18	-54.11	9,000.01	0.01
LZ_SOUTH	1416.18	-54.11	9,000.01	0.01
LZ_WEST	1416.18	-54.11	9,000.01	0.01

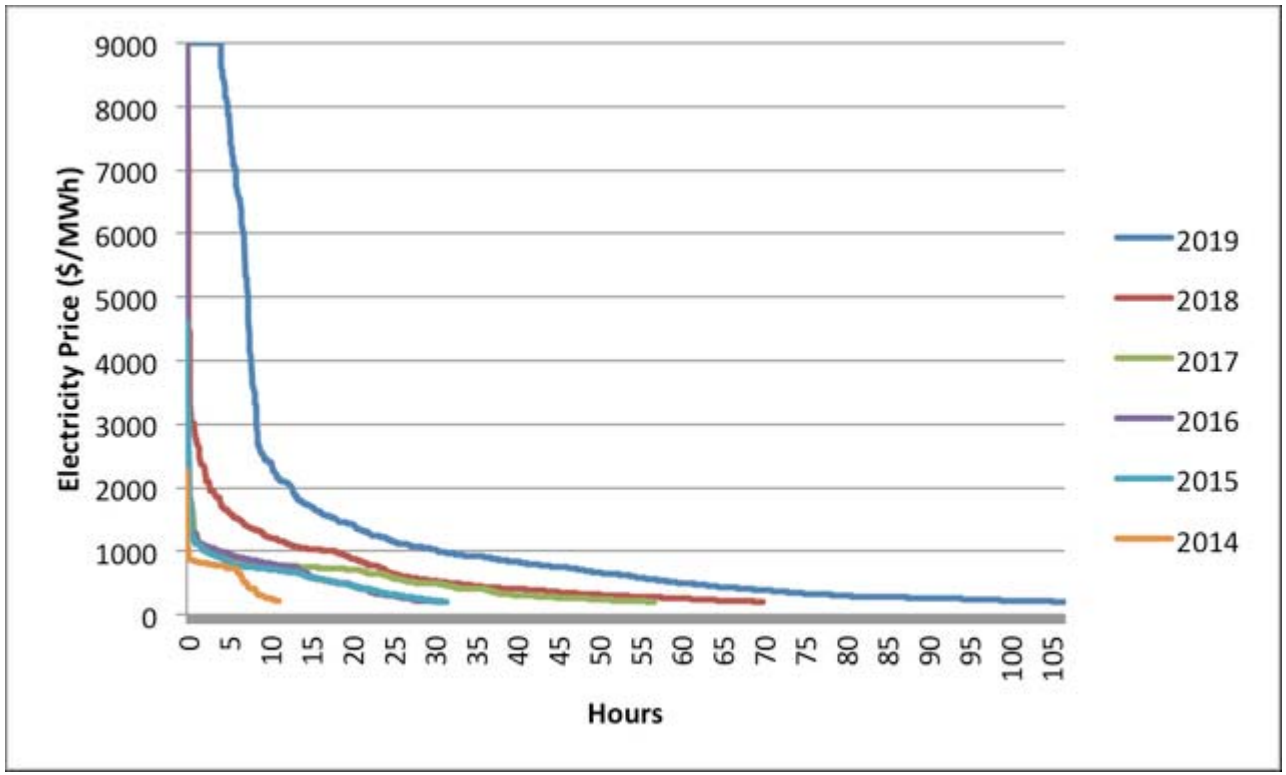
ERCOT

ERCOT PRICE CAP



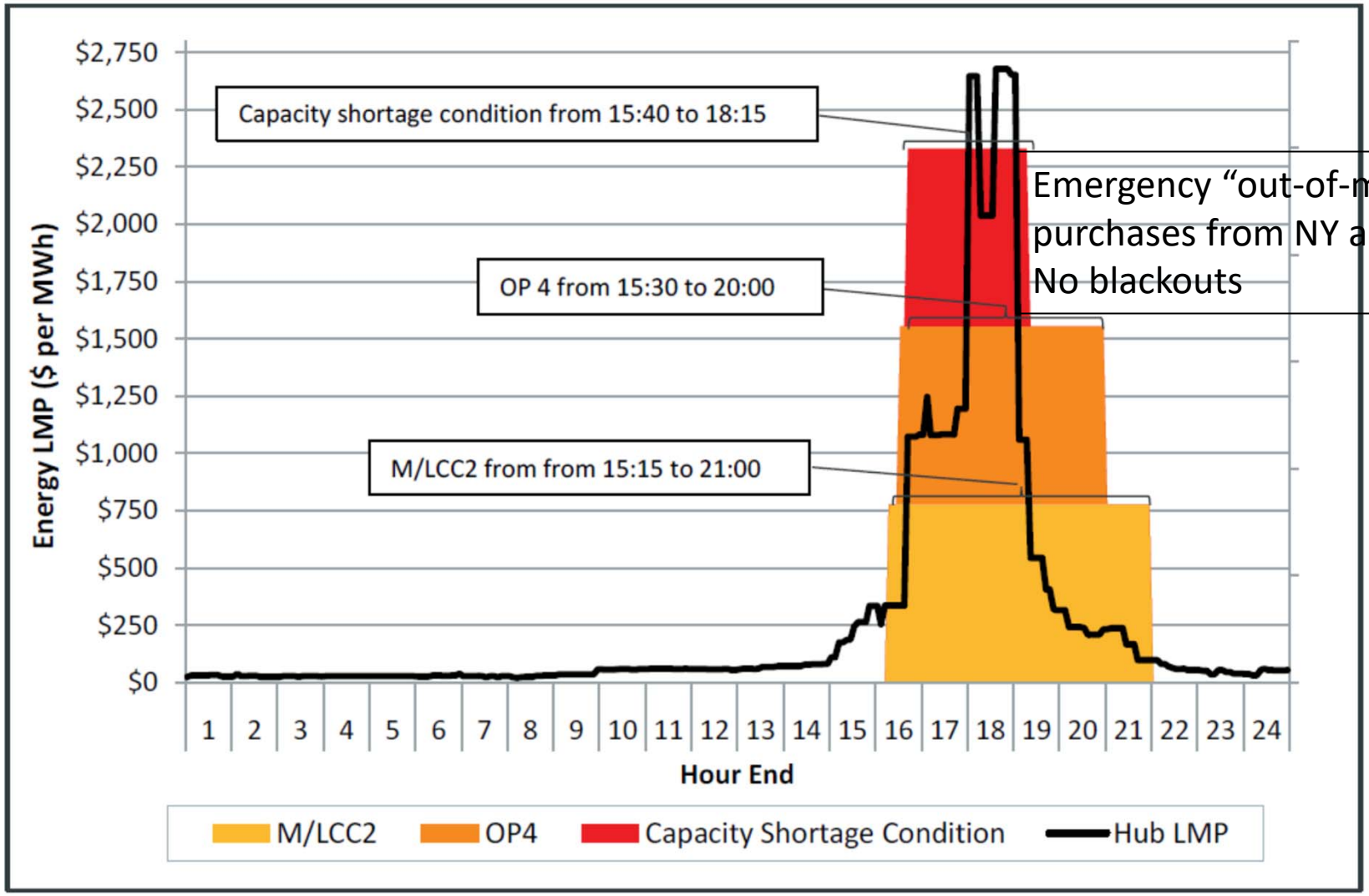
ERCOT

ERCOT PRICE DURATION CURVES 2014-2019 Highest 100 Hours



Source: Schneider and Goggin, Grid Strategies LLC, October 14, 2019, updated March 23, 2020

Figure 5-1: System Event Categories and Real-Time Pricing Outcomes



Emergency "out-of-market" purchases from NY and NB
No blackouts

ISO-NE September 3, 2018

Demand higher than forecasts
+ Unplanned generator outages

What Happened in ERCOT February 14-19, 2021?

- Extreme cold wave ("Arctic Vortex"), rain, ice, snow affecting Texas and adjacent areas
- Weather sensitive electricity demand (electric heat) increased significantly exceeding worst case reliability assessment values
  - Base case peak winter demand 57,000 MW
  - Extreme weather case 67,000 MW
  - Actual (estimated) 77,000 MW
- Weather sensitive natural gas demand also increased significantly
- Similar events in 2011 but much more extreme, widespread, or long-lasting
- Many failures on the supply side primarily due to extreme weather
  - Many generators (gas, coal, nuclear, wind) broke down or froze as valves, pipes, control mechanisms, turbine blades, etc. froze
  - Some gas supply curtailments
    - Equipment failures (?)
    - Demand priority (?)
  - Some transmission and network limitations

Outage Cause Categories

- **Existing Outages**: Generator outages or derates that started before the issuance of the Operating Condition Notice on February 8, 2021; includes ongoing planned and forced outages as well as seasonally mothballed units. Some existing outages ended before or during the event, allowing the unit to return to service.

- **Fuel Limitations**: Generator outages or derates due to lack of fuel, contaminated fuel, fuel supply instability, low gas pressure, or less efficient alternative fuel supply.

- **Weather Related**: Generator outages or derates explicitly attributed to cold weather conditions in the RFI responses. This includes but is not limited to frozen equipment—including frozen sensing lines, frozen water lines, and frozen valves—ice accumulation on wind turbine blades, ice/snow cover on solar panels, exceedances of low temperature limits for wind turbines, and flooded equipment due to ice/snow melt.

ERCOT, April 6, 2021

Outage Cause Categories *(continued)*

- **Equipment Issues**: Generator outages or derates due to facility equipment failures or malfunctions not explicitly attributed to cold weather in the RFI response. This includes trips and derates related to control system failures, excessive turbine vibrations, or other equipment problems.

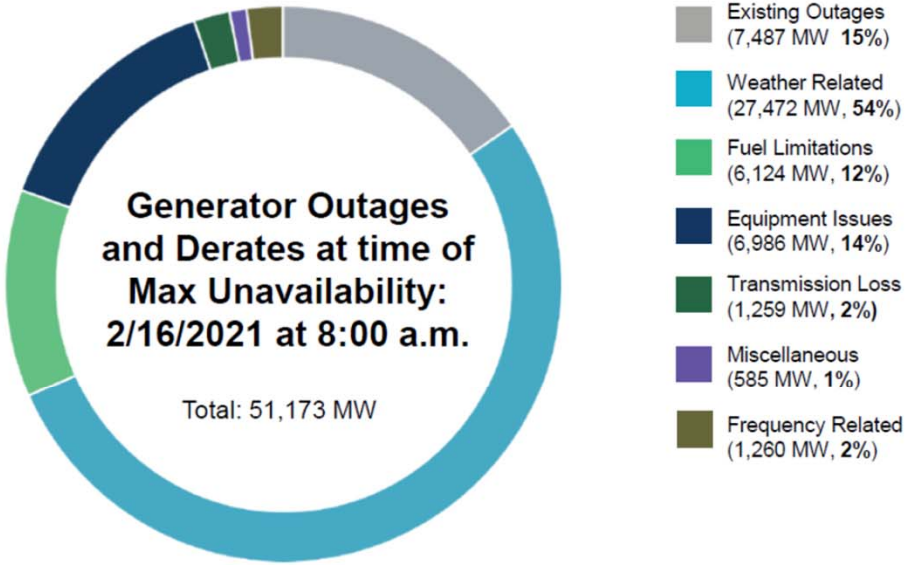
- **Transmission Loss**: Generator outage or derates due to forced outages on directly connected transmission facilities.

- **Frequency Related**: Generator outage or derates attributed to frequency deviations from 60Hz; includes automatic tripping due to under-frequency protection relays and any automatic or manual tripping attributed to plant control system issues related to frequency deviation.

- **Miscellaneous**: Other generator outages or derates not linked to one of the above causes, including outages for which a cause is yet unknown.

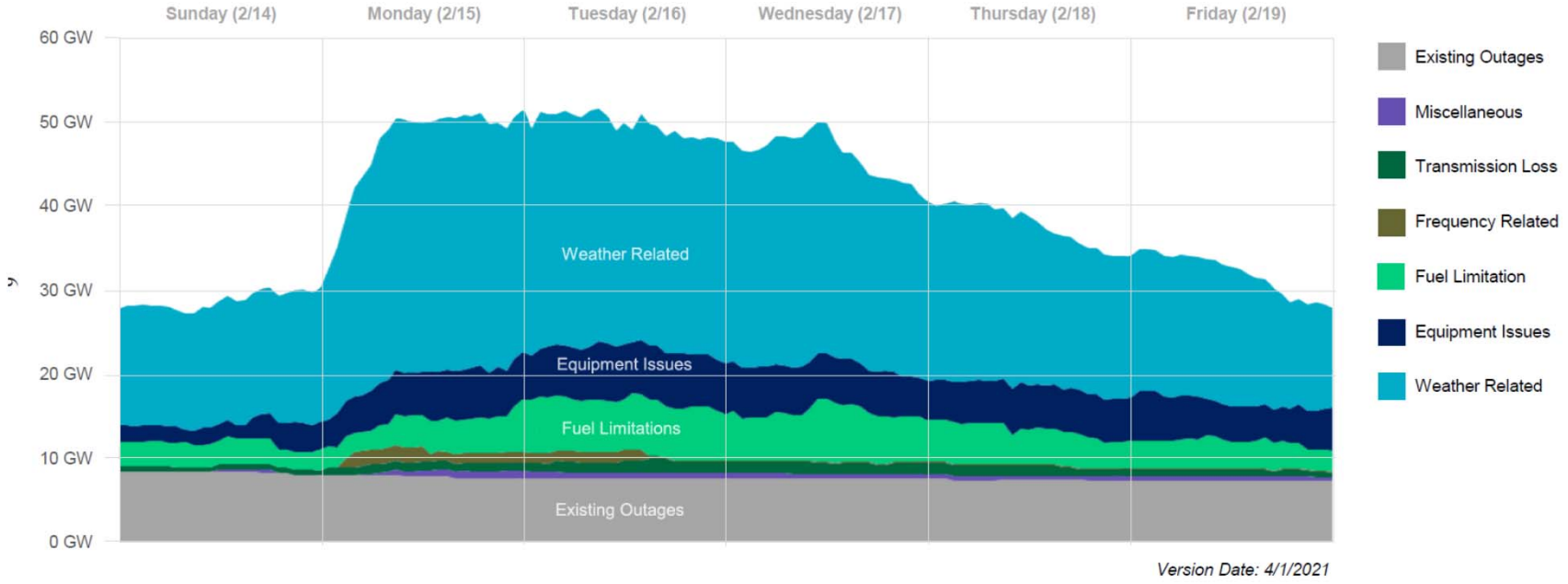
Generator Outage and Derates: Maximum Unavailability

- The highest amount of unavailable capacity during the period of February 14-19, 2021 occurred on February 16 at ~8:00 AM and was 51,173 MW.
- This chart shows the MW of the generator outages or derates that were occurring at that point in time by cause category.
- Note that the total outaged and derated capacity at this time is different than what was previously reported (52,277 MW) due to additional information received in response to the RFIs.



Net Generator Outages and Derates by Cause (MW)

February 14 – 19, 2021



Version Date: 4/1/2021

Net generator outages at the beginning of each hour on February 14-19, 2021, by cause category.

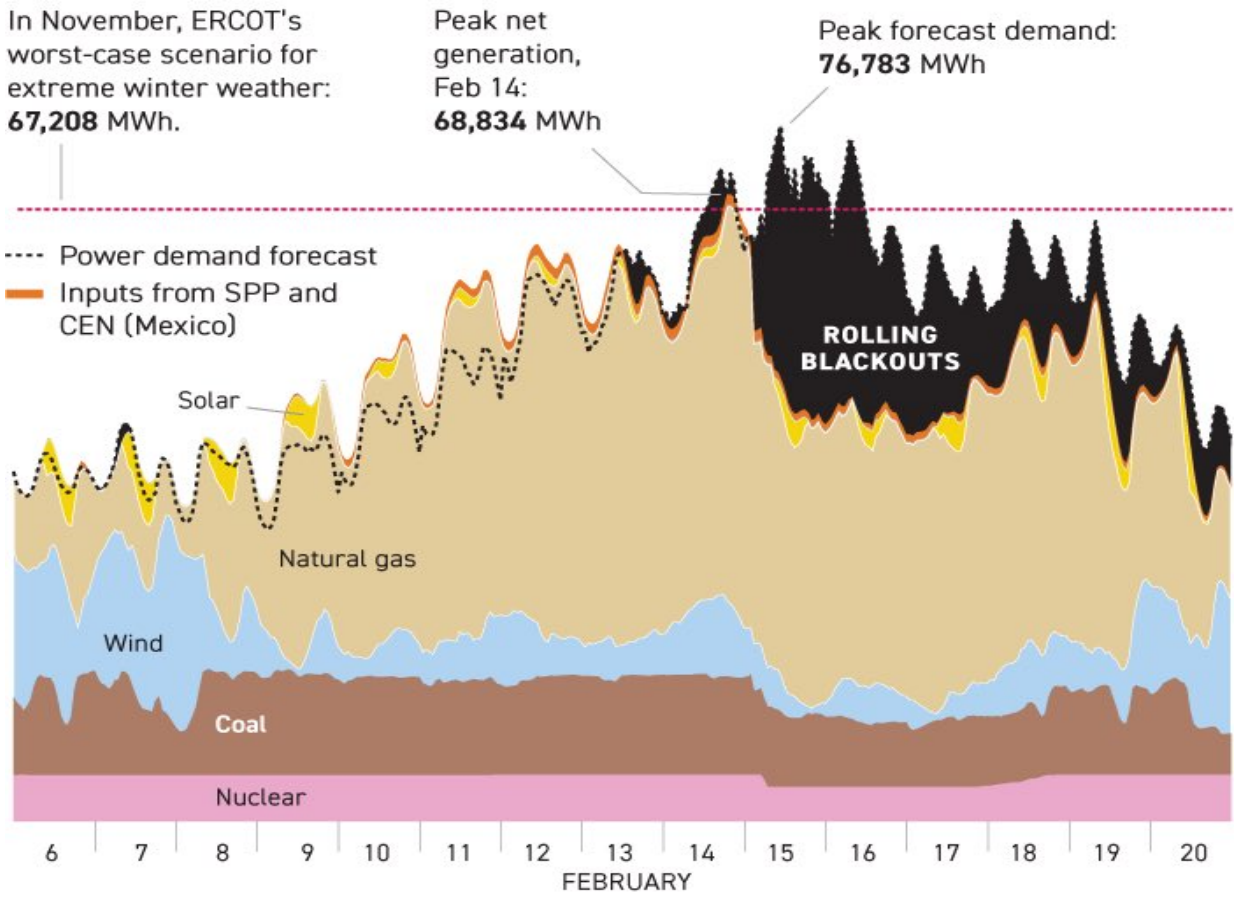
ERCOT, April 6, 2021

What Happened in ERCOT February 15-18, 2021?

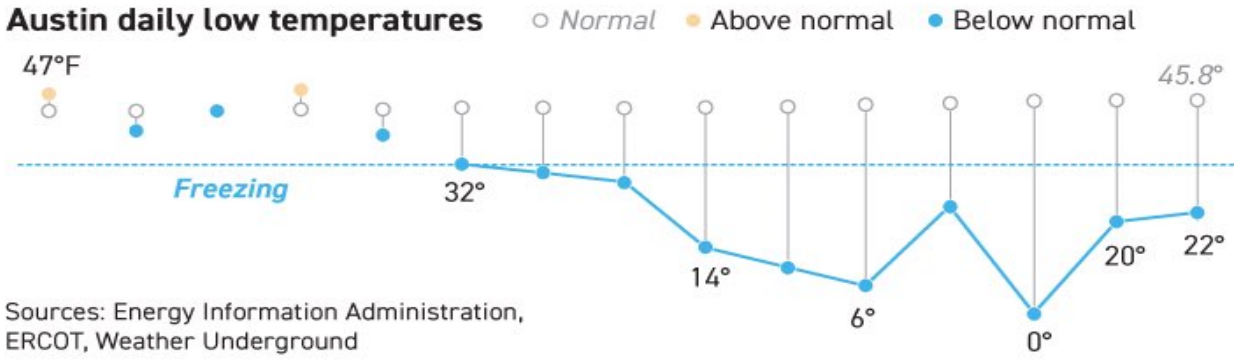
- Outages of generating plants plus extreme demand led to significant operating reserve deficiencies starting at about 1:00 AM on February 15
- Operating reserve deficiencies led network frequency to decline and led to rolling blackouts starting at 1:20 AM on February 15
  - 10,400 MW initially
  - 20,000 MW later in the day
- Load shed was too large to "roll" and some customers lost power for as much as 70 hours
- Came close to a total system collapse on February 15 as frequency dropped below criterion (4 minutes from collapse)
- Blackouts continued into early February 19
  - About 4 million households and businesses lost power
  - Fatalities: 50 to 150 --- estimates vary
  - Clean water supplies disrupted
  - Costly loss of economic activity ($200-$300 billion)
  - ERCOT CEO and Board resigned
  - Members of PUCT Resigned
- PUCT ordered prices to be set at the price cap ($9,000) as long as there were rolling blackouts or brownouts
- Potentially large financial impacts on some generators and retail suppliers
  - Depends on contracting position and outage situation
  - Bankruptcy filings are starting

A cold knockout to the Electric Reliability Council of Texas

NET GENERATION AND FORECAST DEMAND, IN MEGAWATT-HOURS

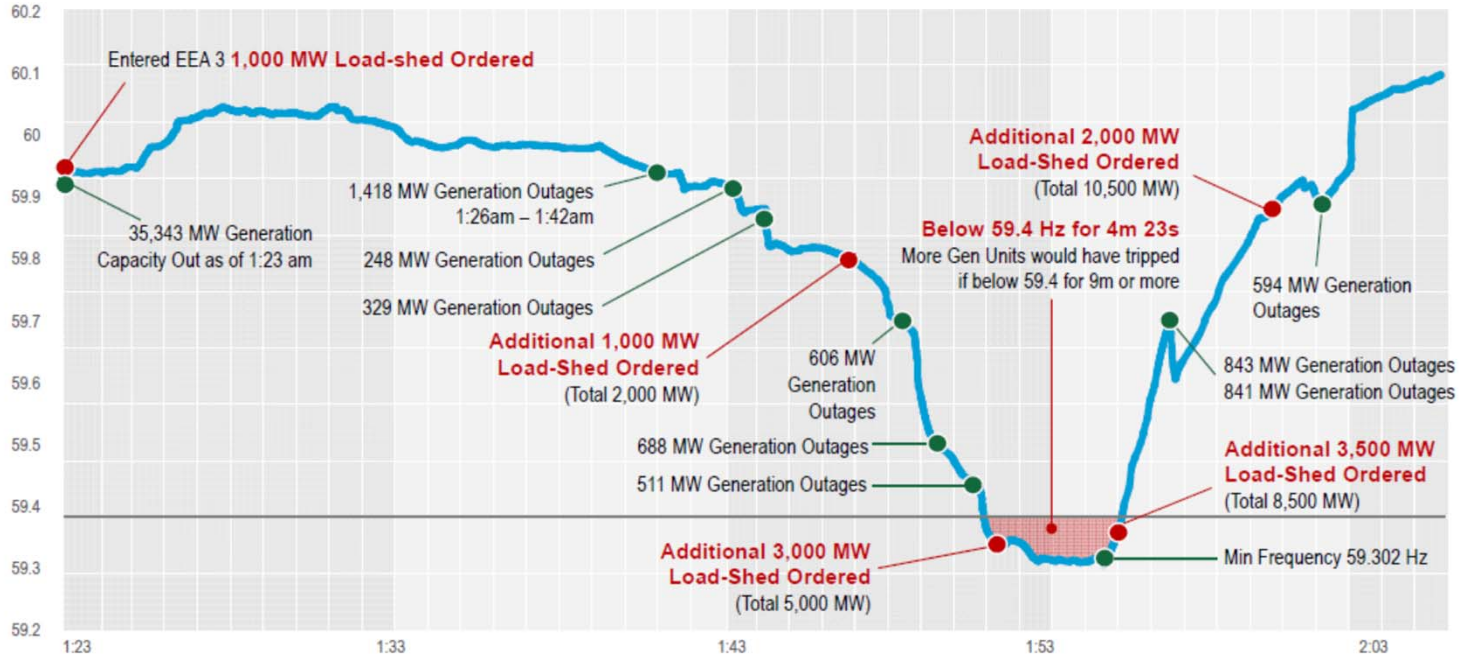


Austin daily low temperatures



Sources: Energy Information Administration, ERCOT, Weather Underground

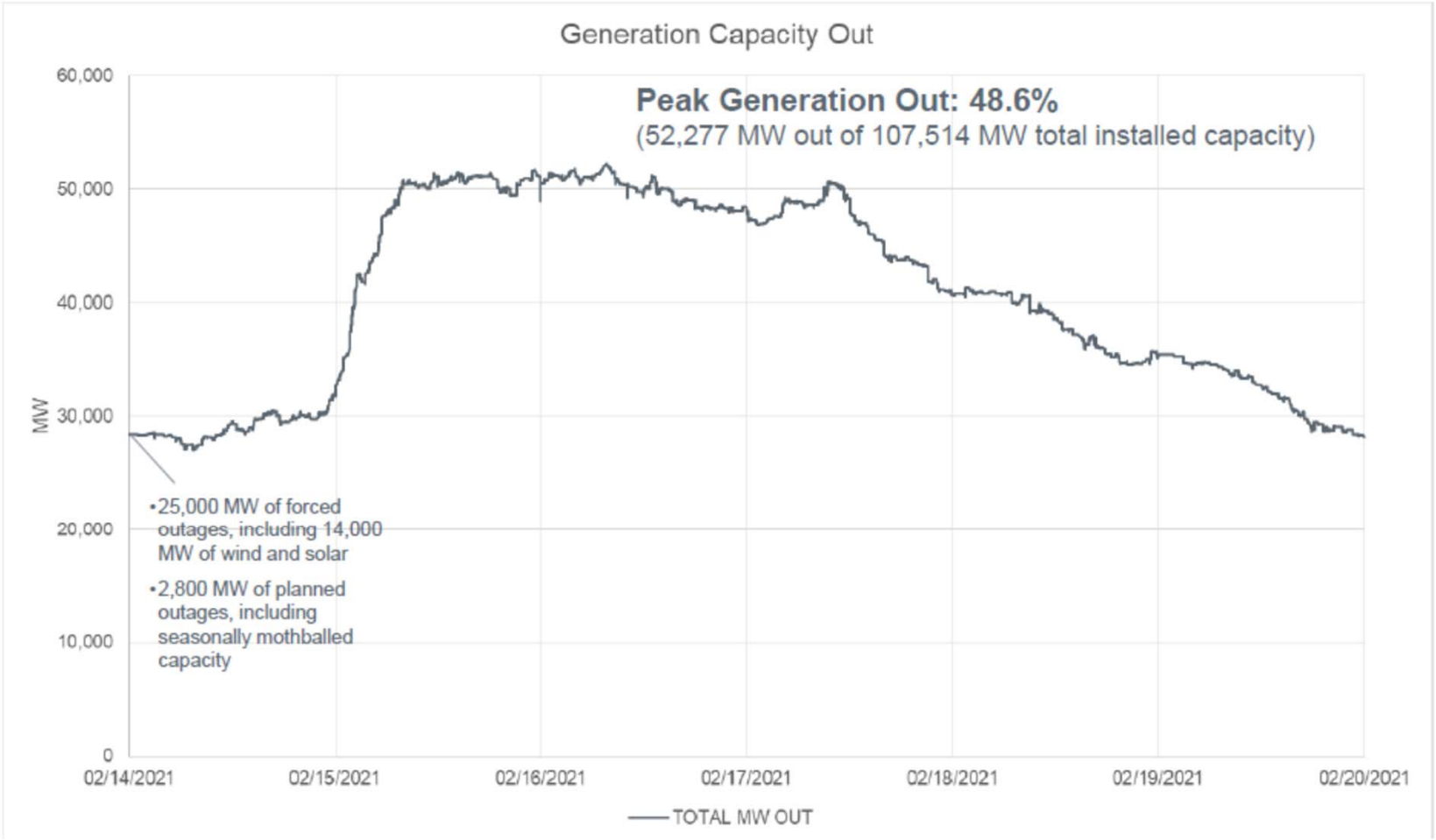
Rapid Decrease in Generation Causes Frequency Drop



ercot

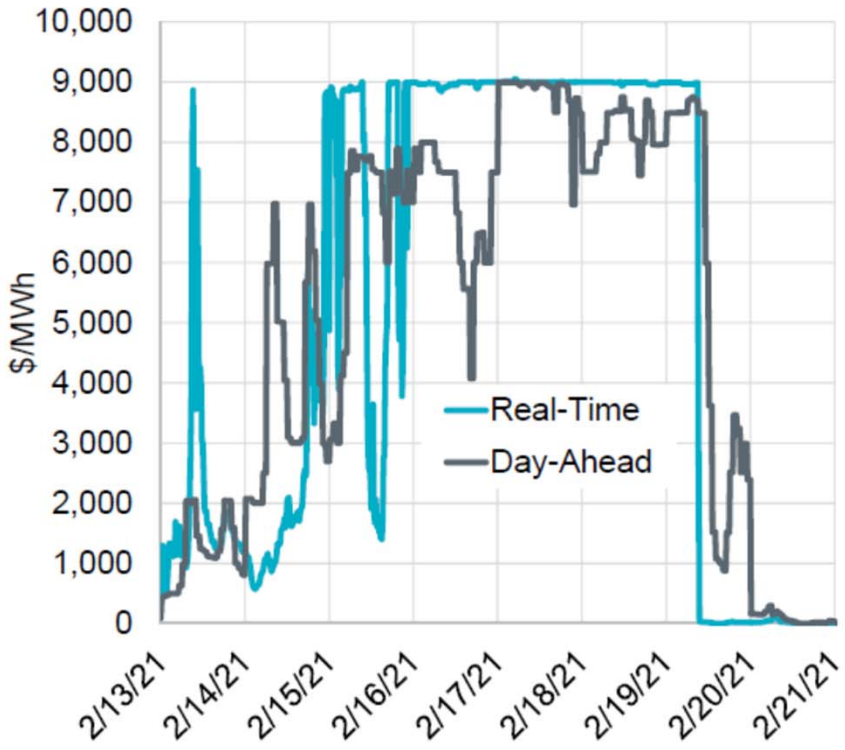
ERCOT

Generation Capacity Out February 14 – 19, 2021



ERCOT

Real-Time and Day-Ahead System-Wide Pricing



Average system-wide pricing around the event relative to other historical periods (in $/MWh)

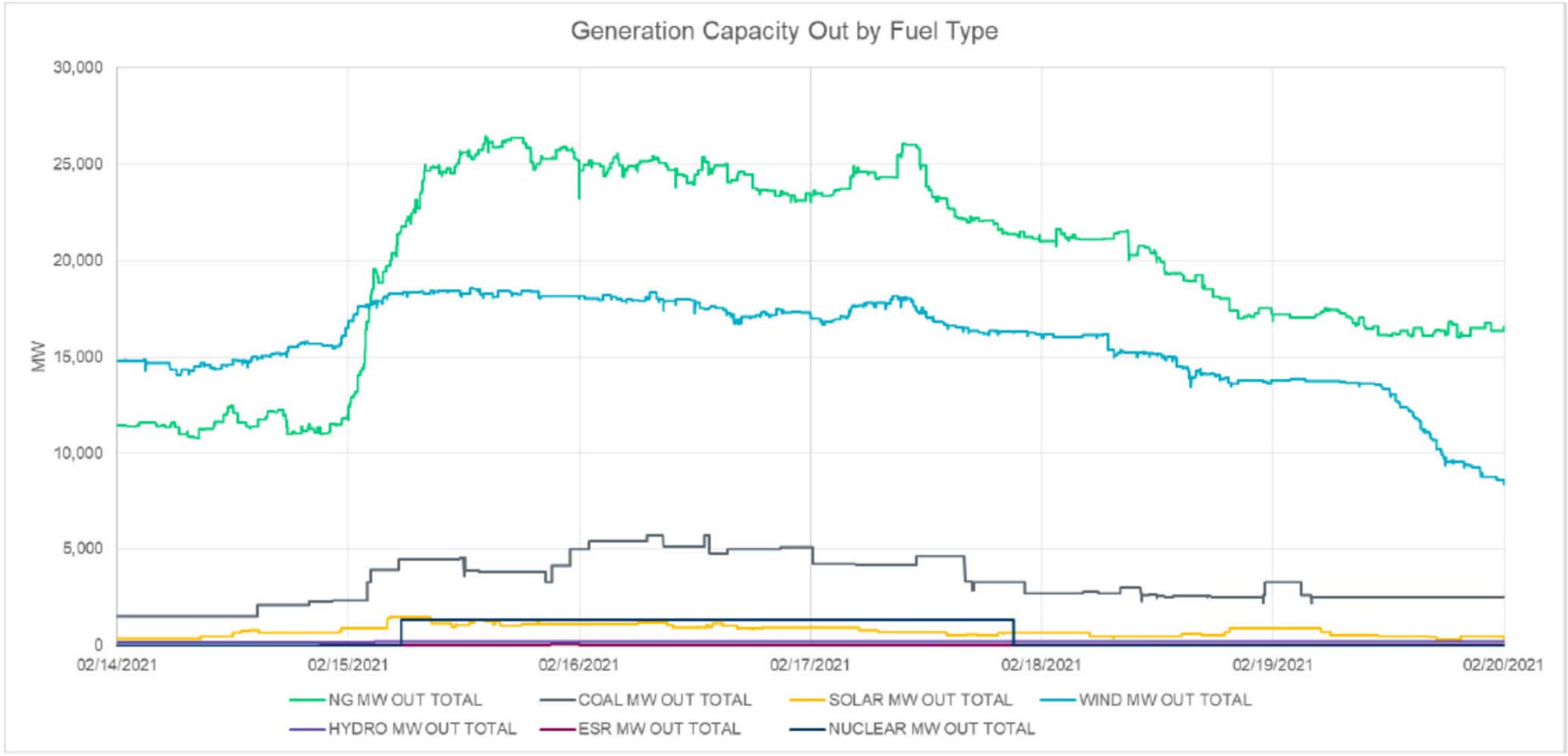
Date Range	Real-Time	Day-Ahead
2/14/21 2/19/21	$6,579.59	$6,612.23
January '21	$20.79	$21.36
February '20	$18.27	$17.74

This data is using the ERCOT Hub Average 345-kV Hub prices

The Blame Game

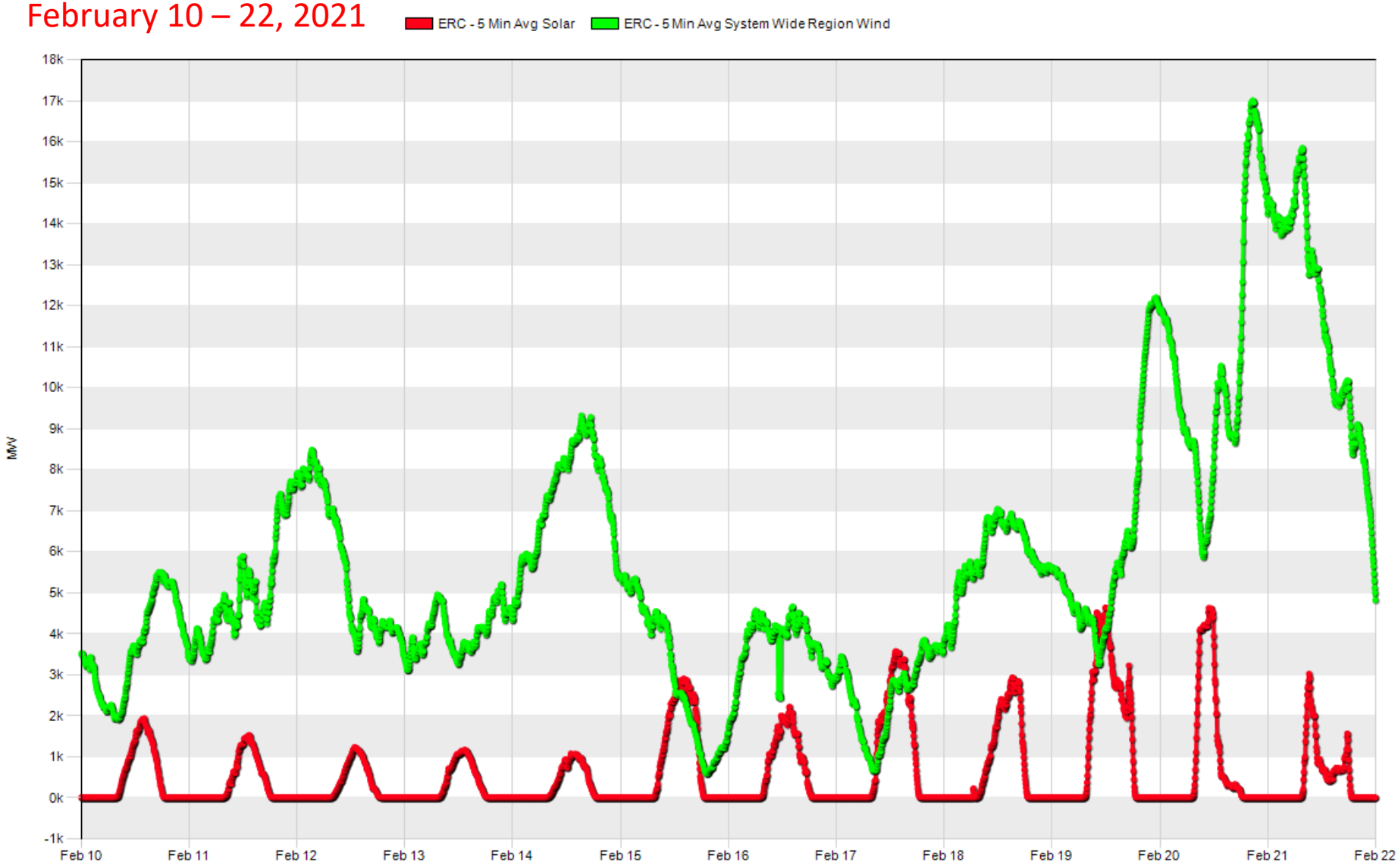
- This was a very bad failure of the electric power system in ERCOT that exceeded all market design parameters
- Was the problem the growing supplies from intermittent wind and solar?
  - No
  - Unplanned outages of fossil and nuclear generation were more important
  - There were unplanned outages of wind but winter reliability assessments assumed only about 6 GW of wind

Generation Capacity Out by Fuel Type



ERCOT

ERCOT Wind and Solar Generation
February 10 – 22, 2021



Created with NRGStream Trader 8

Was it the ERCOT Market Design?

- Not directly (or narrowly); the market design did not anticipate the extensive failure of the underlying electricity and gas infrastructure that dominated the crisis
  - A capacity market would not have led to a fundamentally different outcome with the same underlying assumptions about supply, demand, VoLL, etc.
    - The implicit VoLL in ISOs with capacity markets is much higher than $9,000/MWh and reserve margin targets are typically also significantly higher
    - The price caps are < $2,000/MWh to set LMP and <$2,500 to call specific generators per FERC Order 831
    - Other ISOs have policies and incentives for fuel security and weatherization
    - Coordination of gas and electricity systems is an issue everywhere in the U.S.
- These events may have political implications for scarcity pricing design in ERCOT and expansion to other regions
  - Evaluating “circuit breakers”
- Incentive effects of $9000/MWh prices under these extreme conditions would benefit from more empirical analysis
  - Can’t reduce your demand if you are blacked out
  - No incentive to shift demand between hours within the day
  - Incentives to attract “industrial” generation to the system were may be muted by outage uncertainties
  - Weatherization and backup-fuel incentives for generators were likely muted by failures on the gas system
  - Hedging incentives are complicated
  - Incentive vs. redistributive effects TBD

Some Proposed Responses to Extreme Weather Events

- Evaluate circuit breakers for price caps
- Incentives or regulation to “weatherize” generating plants
- Incentives or regulation to add dual-fuel and fuel storage capabilities to generating plants
- Improve coordination between gas and electricity markets
- Incentives or regulation to “weatherize” gas pipeline system
  - Place gas pipeline compressors on the “no blackout” list (if feasible) or require backup generators for compressors
- Build emergency reserve generation (Warren Buffet) with fuel storage --- CREZ as an earlier departure from Laissez-Fair
  - Berkshire-Hathaway:$8.3 billion for 10 GW of standby generation + gas storage. 9.3% ROR over 40 years recovered as a customer charge
- Increase storage capacity
- Expand interties with Eastern and/or Western Systems

Generation Weatherization

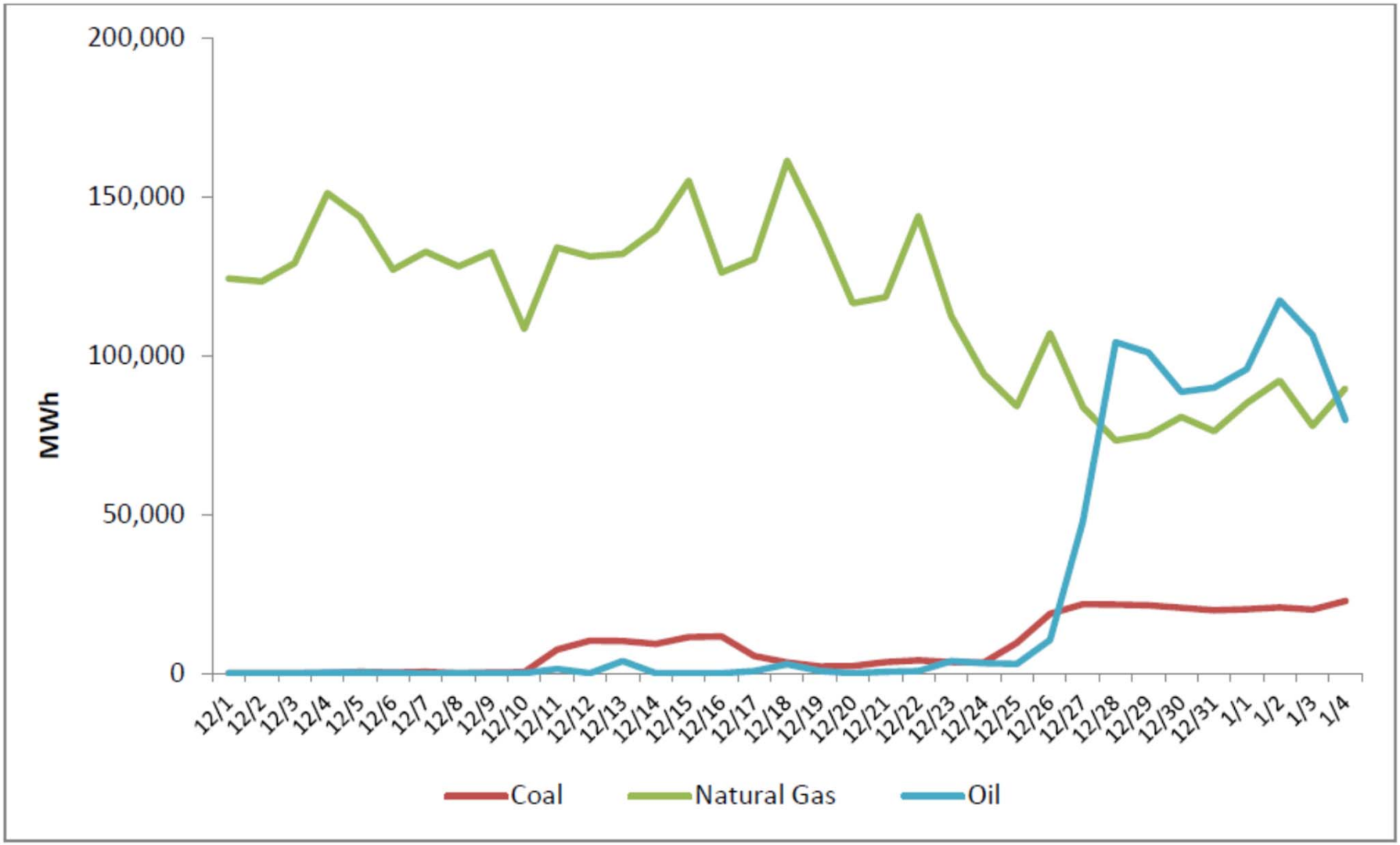
- Generation owners and operators are not required to implement any minimum weatherization standard or perform an exhaustive review of cold weather vulnerability. No entity, including the PUC or ERCOT, has rules to enforce compliance with weatherization plans or enforce minimum weatherization standards.
- In 2011, the PUC amended its rules to authorize ERCOT to conduct generator site visits to review compliance with weatherization plans. Spot checks include reviewing the weatherization plan, verifying that plant personnel are following the plan and providing recommendations based on PUC requirements, lessons learned or best practices.
- We currently perform spot checks at power plant units at the rate of about 80/year. Whenever possible, a Texas Reliability Entity (TRE) representative joins ERCOT for these spot checks.
- While we request and review detailed plant records, the only entity that can confirm that a plant is “weatherized” to any particular standard is the entity that owns or operates the plant.
- Each year, TRE and ERCOT host an annual workshop on weatherization with generation owners to review lessons learned and best practices.

Pasadena (Texas) Power Plant
NG CCGT
Calpine

Fore River Energy Center (Massachusetts)
Dual-fuel (NG/Diesel) CCGT
Calpine

ISO-NE 2017-2018 Northeast Cold Spell

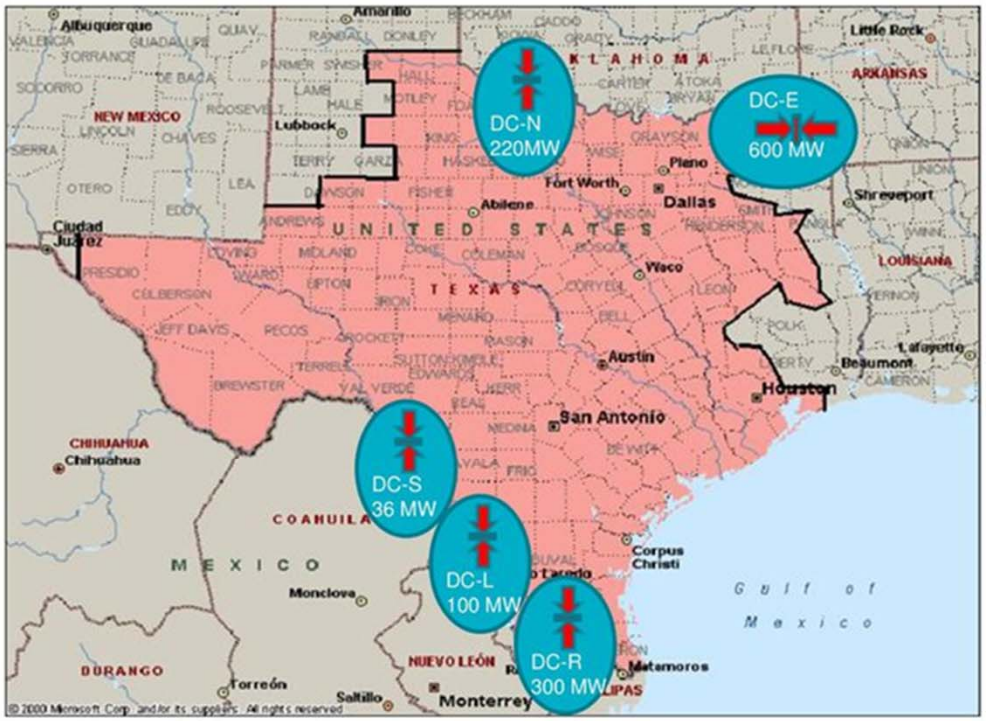
Figure 2: Daily Generation by Fuel Type



ISO-NE

Current ERCOT DC Ties overview

- ERCOT - SPP (North, East)
- ERCOT - Mexico (CENACE) (South, Laredo, Railroad)



ercot

ERCOT
DC-TIE OPERATIONS

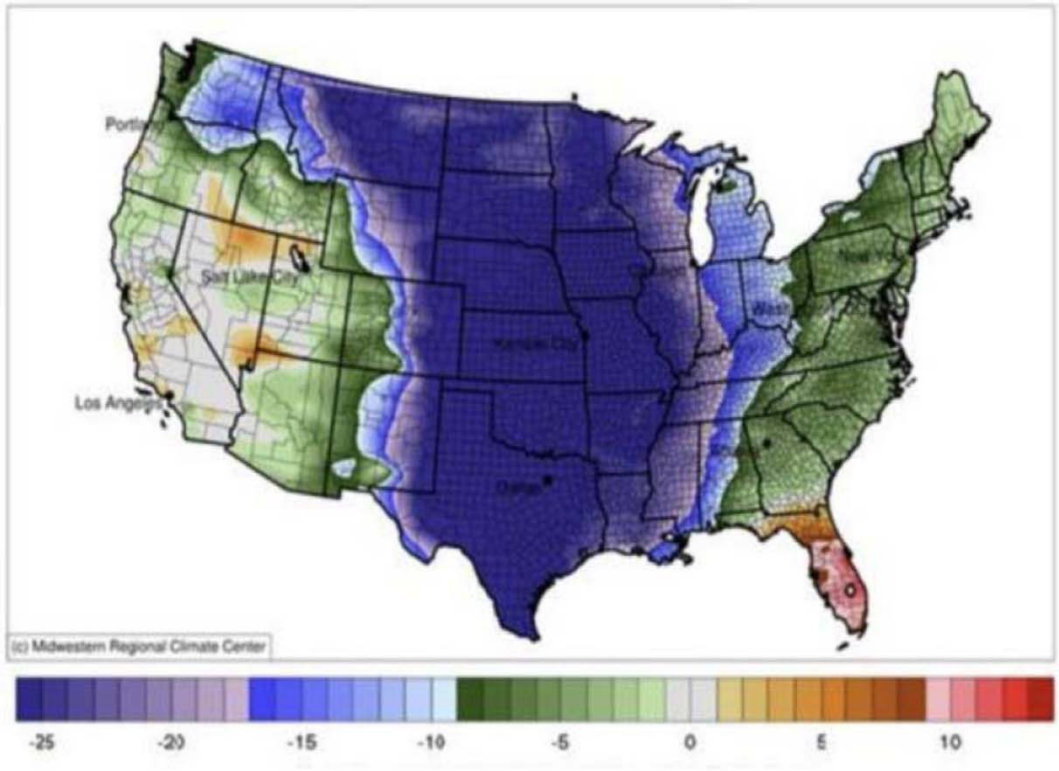
NERC Tagging, Interchange Scheduling, Normal and Emergency Operations, and Inadvertent Energy Accounting

Version 3.0 Rev 8
March 4, 2014

DC Tie	Operator
North	AEP
East	AEP
South	AEP
Laredo	AEP
Railroad	Sharyland

Average Temperature (°F): Departure from 1981-2010 Normals

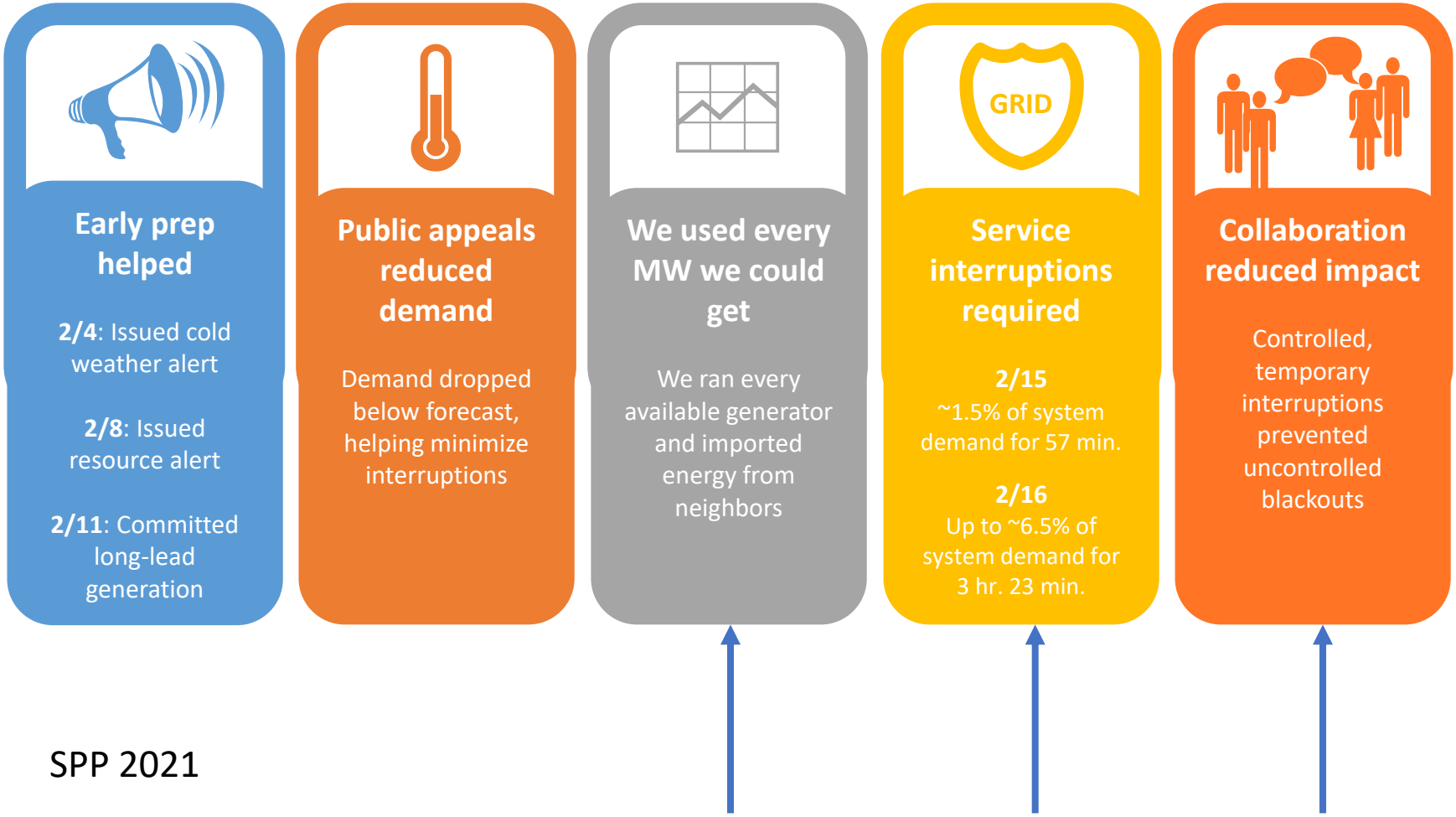
February 12, 2021 to February 18, 2021



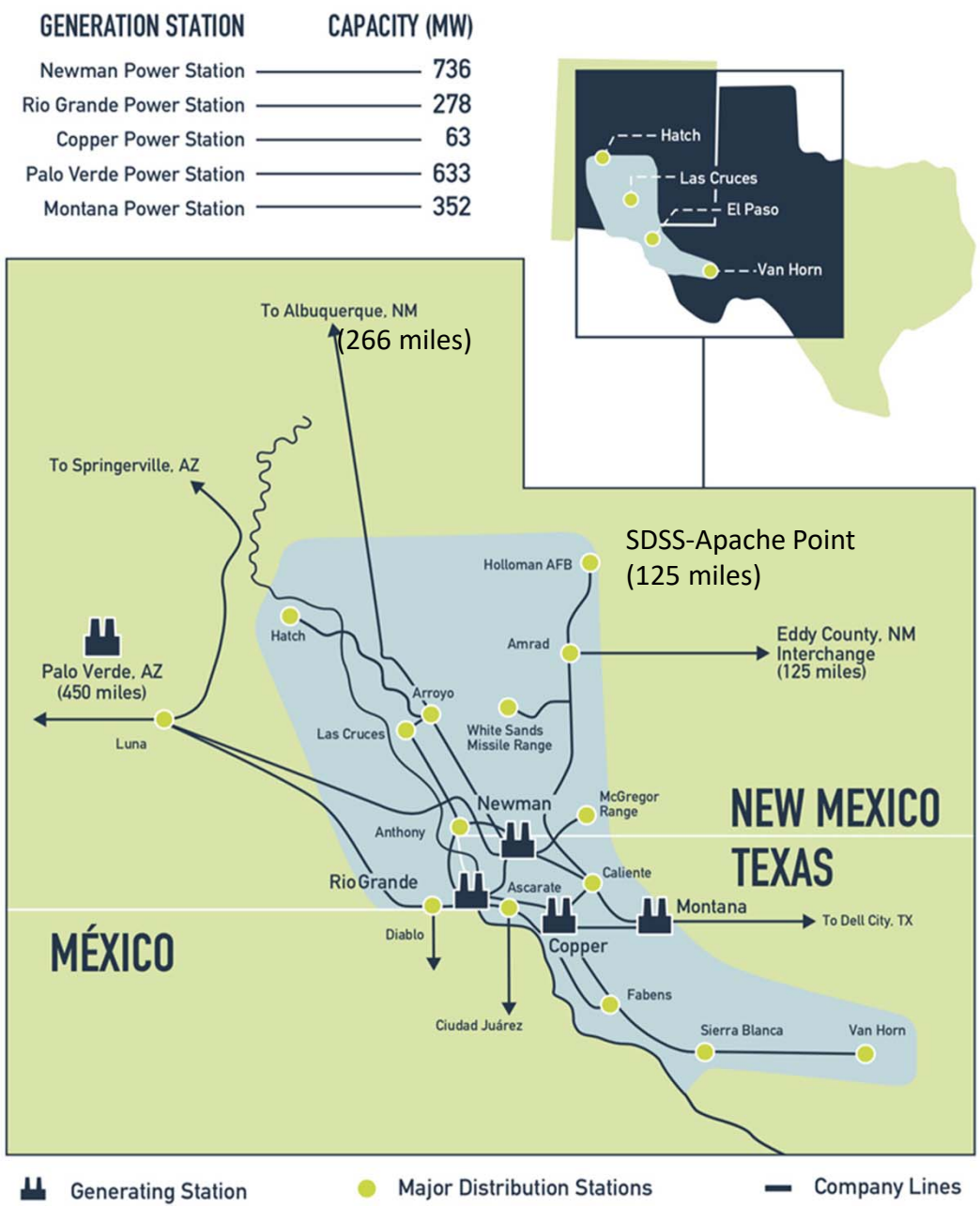
Temperatu

Regional Climate Center

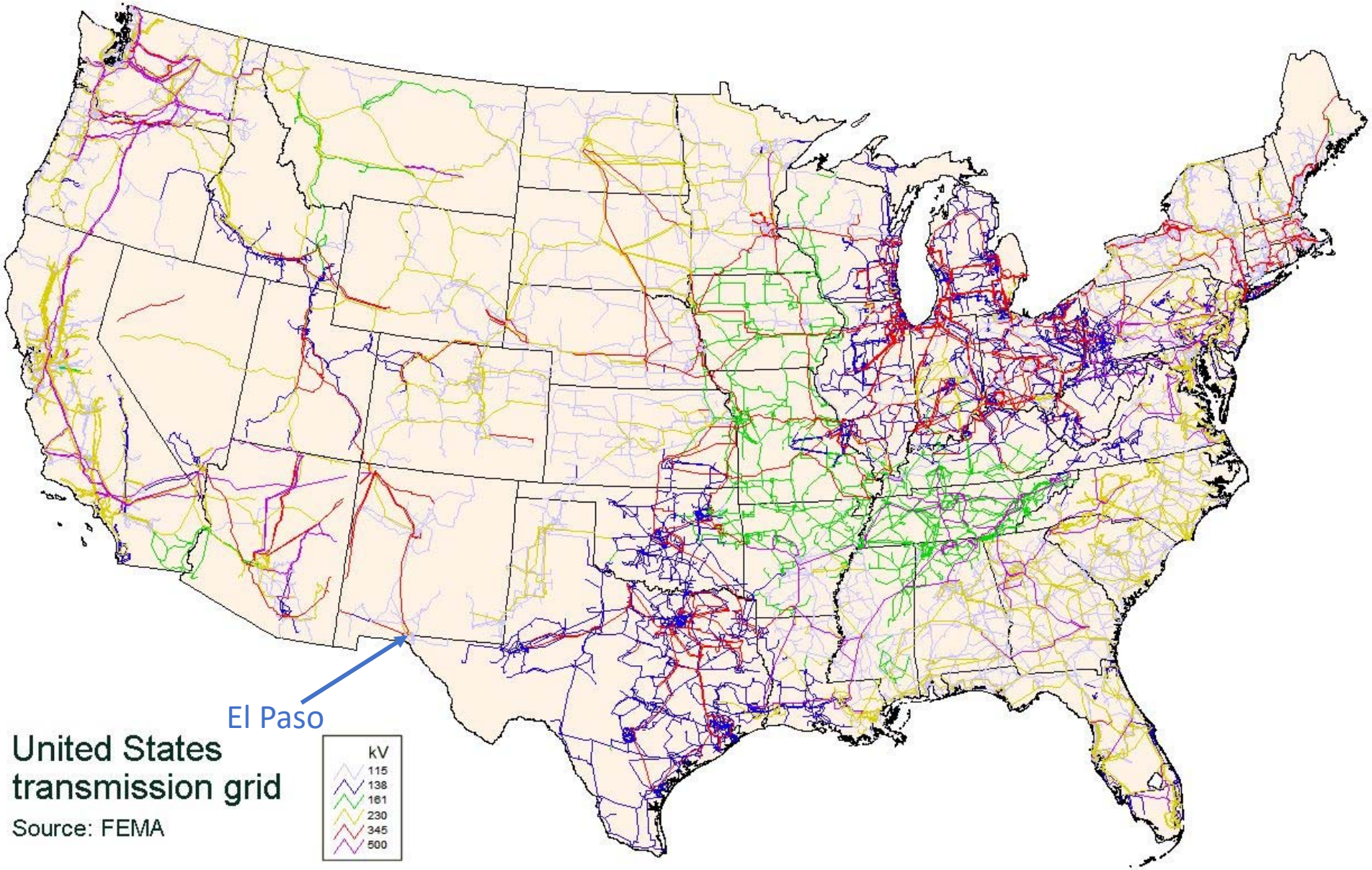
SPP


Early prep helped
2/4: Issued cold weather alert
2/8: Issued resource alert
2/11: Committed long-lead generation
Public appeals reduced demand
Demand dropped below forecast, helping minimize interruptions
We used every MW we could get
We ran every available generator and imported energy from neighbors
GRID
Service interruptions required
2/15
~1.5% of system demand for 57 min.
2/16
Up to ~6.5% of system demand for 3 hr. 23 min.
Collaboration reduced impact
Controlled, temporary interruptions prevented uncontrolled blackouts

SPP 2021



El Paso Electric, https://www.epelectric.com/company/about-epe/service-area


El Paso
United States
transmission grid
Source: FEMA
kV
115
138
161
230
345
500