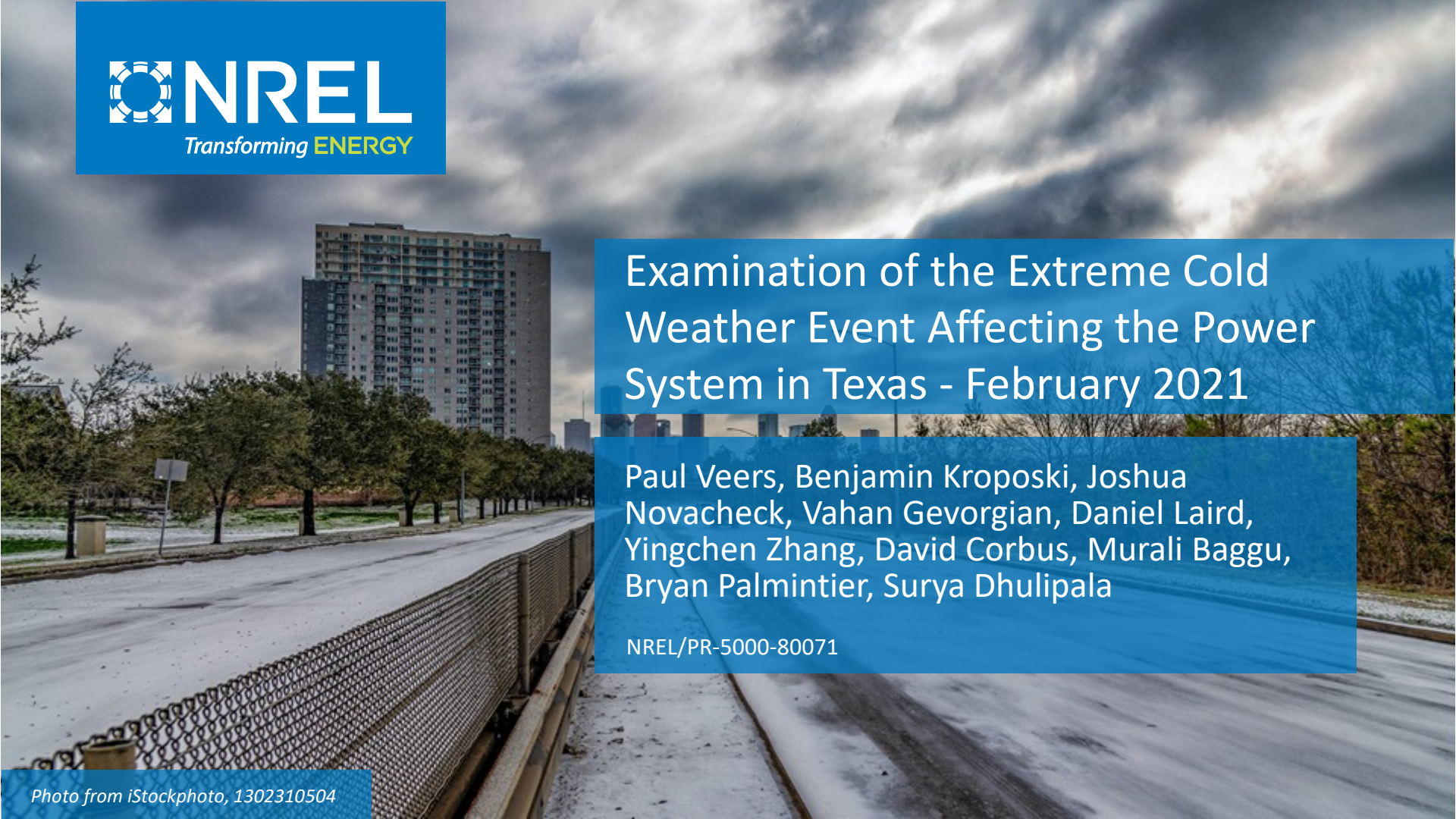

Examination of the Extreme Cold Weather Event Affecting the Power System in Texas - February 2021

Paul Veers, Benjamin Kroposki, Joshua Novacheck, Vahan Gevorgian, Daniel Laird, Yingchen Zhang, David Corbus, Murali Baggu, Bryan Palmintier, Surya Dhulipala

NREL/PR-5000-80071

Photo from iStockphoto, 1302310504

Briefing Outline

- The Big Picture: Perception and Reality
- Wind Turbines and Cold Weather
- Overview of the Event From a Grid Perspective
- Other Extreme Event Studies and the North American Energy Resiliency Model (NAERM)

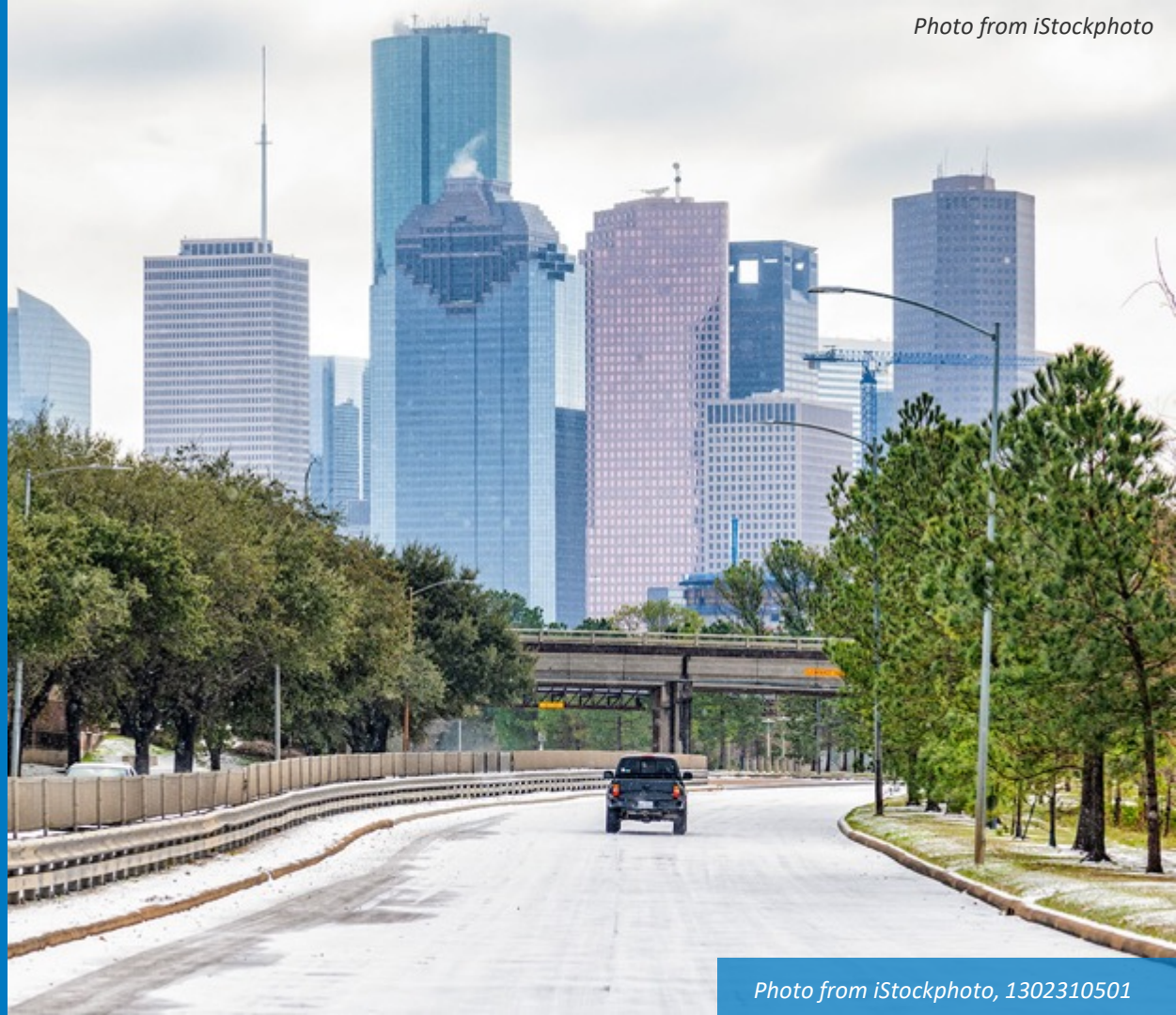

Photo from iStockphoto

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Early Reporting on the Texas Situation Pointed at Renewables

- 15 gigawatts (GW) from wind plants in the northern part of the ERCOT* system were offline due to icing and/or low temperatures during the storm while another 15 GW **continued to generate as forecasted.**
- 15 GW of thermal plants (gas, coal, and nuclear) went offline in rapid succession the morning of February 15, 2021 due to cold weather issues.
- **ERCOT was forced to shed considerable load to avoid a total system blackout.**
- **Headlines** point to “frozen wind turbines” hampering Texas power output.
- **Texas Governor Greg Abbott** blames solar and wind as the cause of the blackouts and warns against greater dependence on renewables.
- **Secondary news feeds repeat the headlines** and point at renewables.

*ERCOT, the Electric Reliability Council of Texas, manages the flow of electric power to more than 26 million Texas customers, representing about 90% of the state’s electric load.

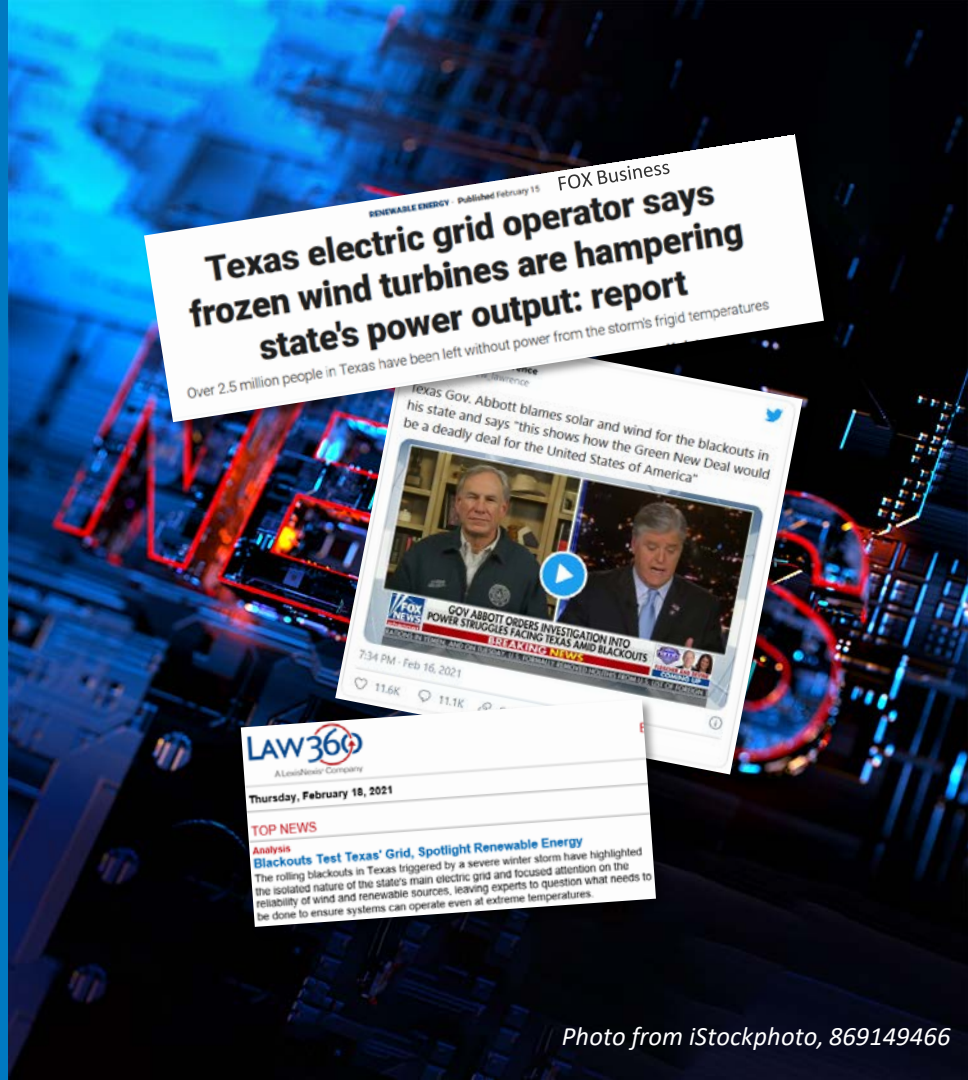


Photo from iStockphoto, 869149466

The Reality: Key Fact-Based Takeaways

The load-shedding event **was not caused by wind plant failure**

Wind turbines **operate regularly in cold weather**

The wind power output was **accurately predicted**

Extreme weather events historically **drive grid reliability**

As a national lab, the National Renewable Energy Laboratory (NREL) has the **capabilities and facilities to help the industry address these types of challenges**

Photo from iStockphoto, 1179839211

Cold-Weather Operation Is a Design Feature for Wind Turbines

- International standards[1] define normal operation as operation at temperatures down to at least -20°C (-4°F).
- Wind turbines are routinely weatherized for cold weather (-30°C or -22°F) and operate well in that weather.
- Cold-weather packages allow operation down to -30°C (-22°F) and include specific features:
  - Heaters for lubricants and bearings
  - Ice-detection systems
  - De-icing systems
  - Anti-icing systems
  - Hardened sensor systems
- Depending on location, installing cold weather packages is a financial decision for the plant developer/operator and not a reliability requirement for the system operator.

[1] International Electrotechnical Commission 61400-1 *Wind turbines – Part 1: Design requirements*

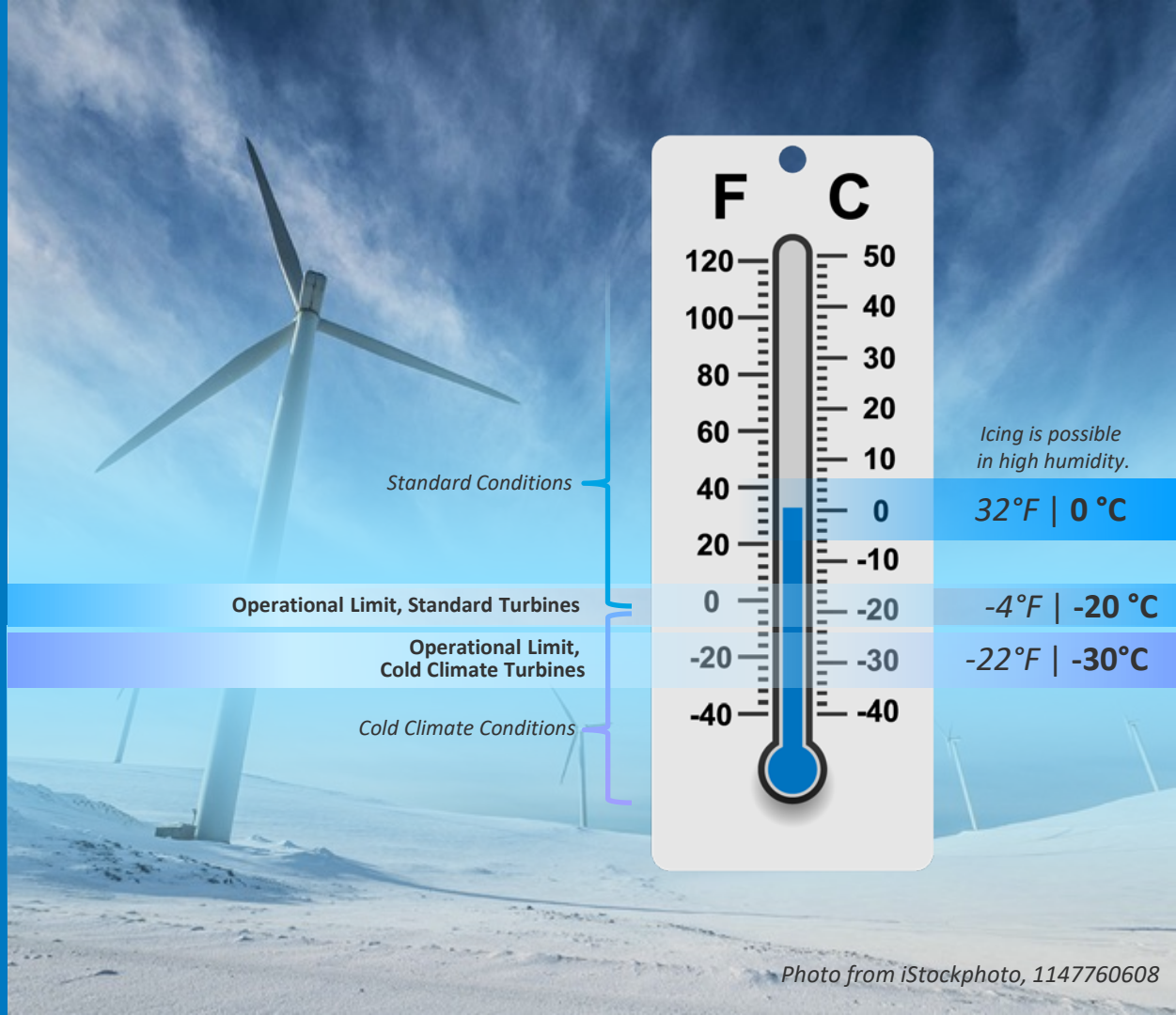


Photo from iStockphoto, 1147760608

What Happened to the Power Grid in Texas?

Photo from iStockphoto, 1302640766

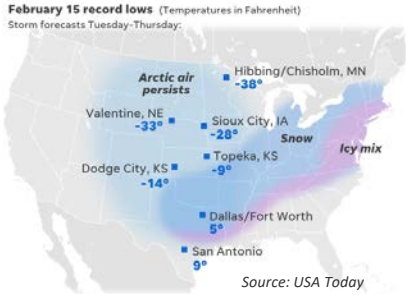
The ERCOT Situation February 15, 2021

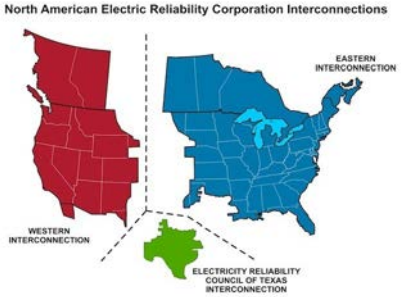
Record cold weather in Texas drove record electricity demand that led to ERCOT shedding a significant amount of load to save the system from a complete blackout across the interconnection.

Typical Winter Peak = 57 GW

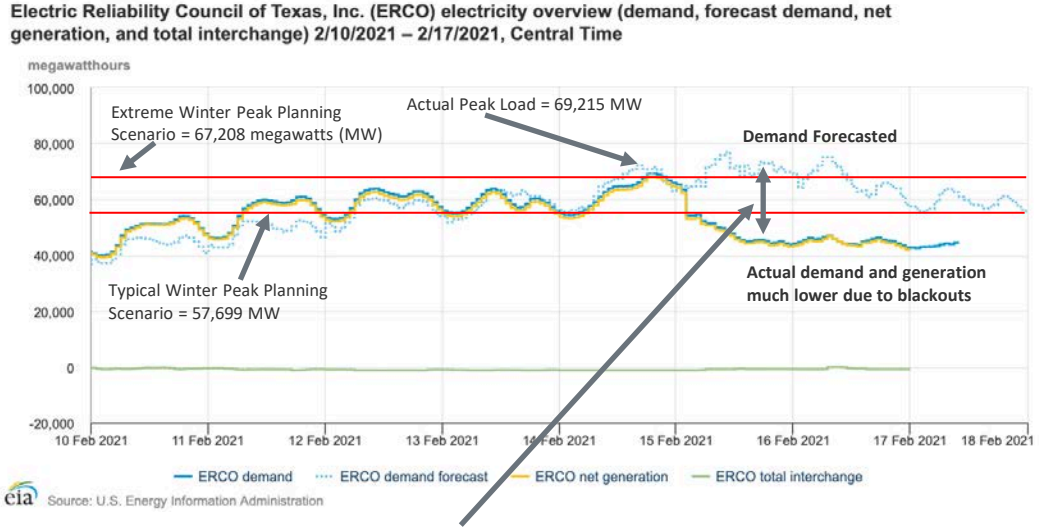
Extreme Winter Peak = 67 GW

Actual Winter Peak = 69 GW





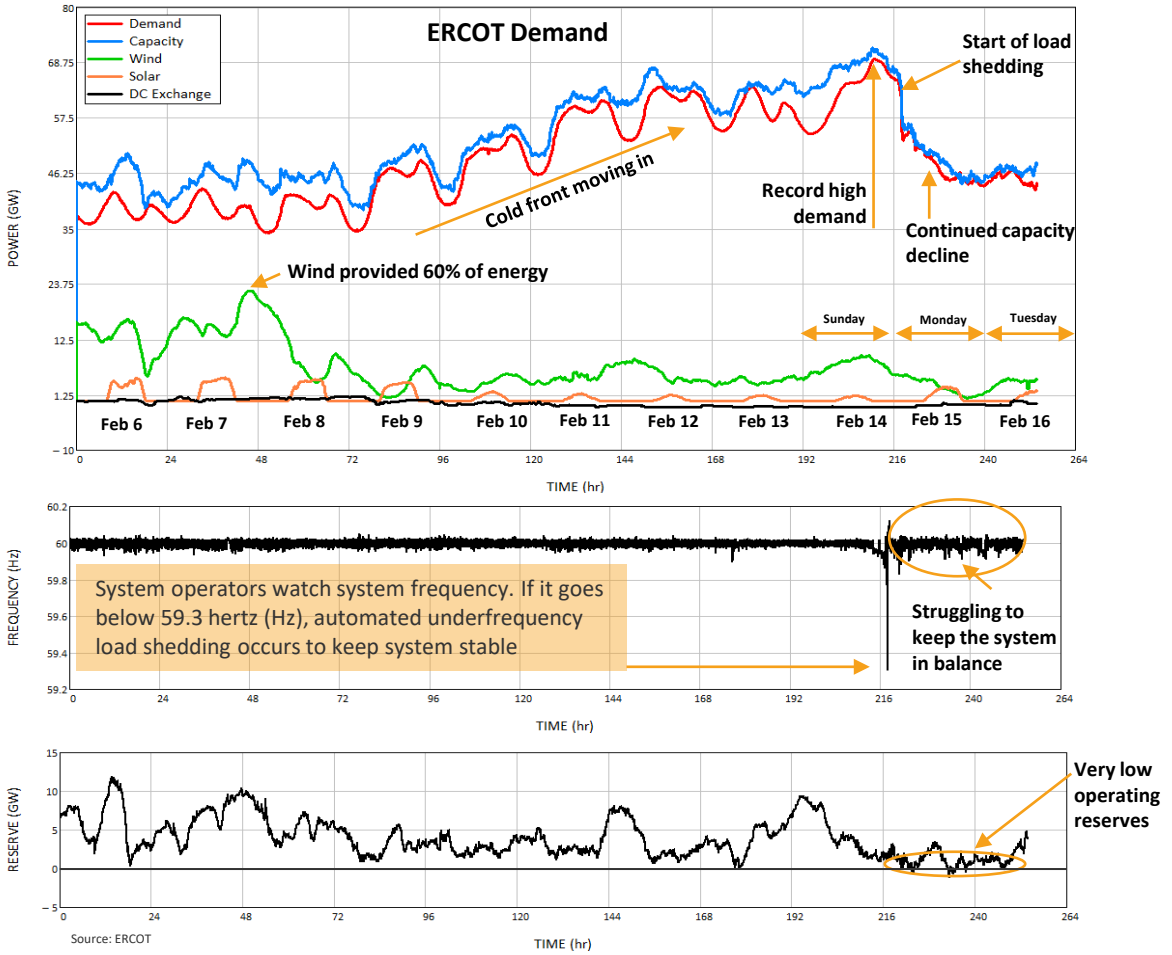
ERCOT operates as a separate AC power grid from the Eastern and Western Interconnections.



Up to 20 GW spread between forecasted demand and actual generation available.

ERCOT Operations February 2021

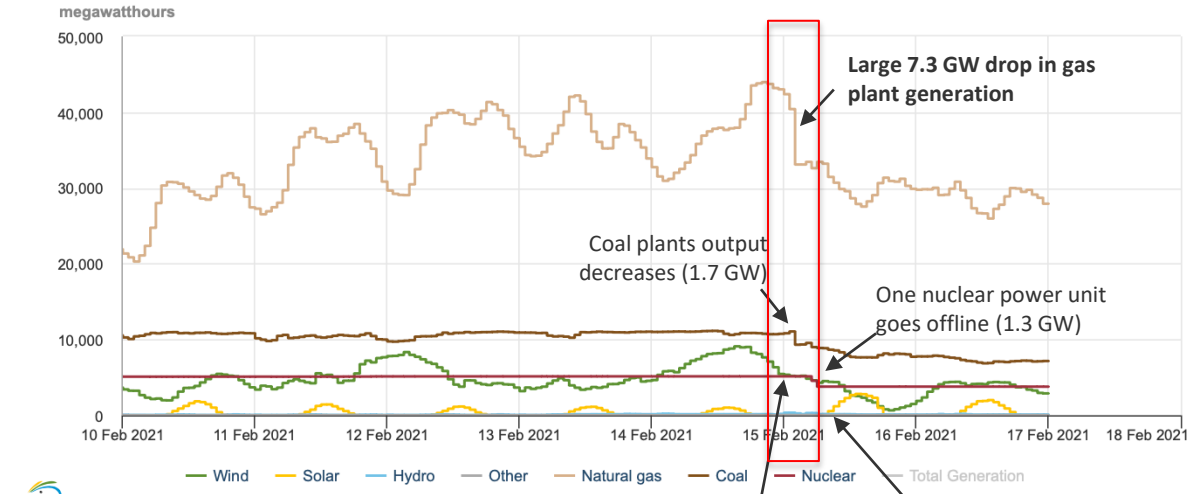
- The load-shedding event was caused by a combination of record-high demand and reduced power generation from plants being removed from the power generation mix because of several cold-weather-related issues.
- Texas wind plants outside of the range of the ice storm were generating and provided more than 5 GW of power throughout the event, similar to the level of wind power generation during the previous week, which was above the total forecast.
- The drop in capacity and subsequent need to initiate load shedding appears to be the result of a sudden drop in outputs from thermal plants.

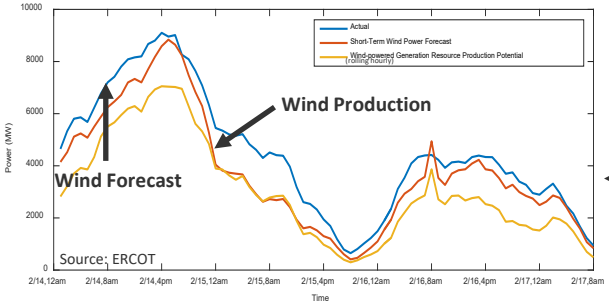


A Closer Look at the Power Generation

- Cold weather impacted the output of all types of power generation during the event.
- Cold weather impacted gas flow and the balance of plant operations at thermal plants.
- Although cold weather started shutting down some wind plants, they performed at near-predicted performance levels on an hour-ahead basis.

Electric Reliability Council of Texas, Inc. (ERCO) electricity generation by energy source 2/10/2021 – 2/17/2021, Central Time





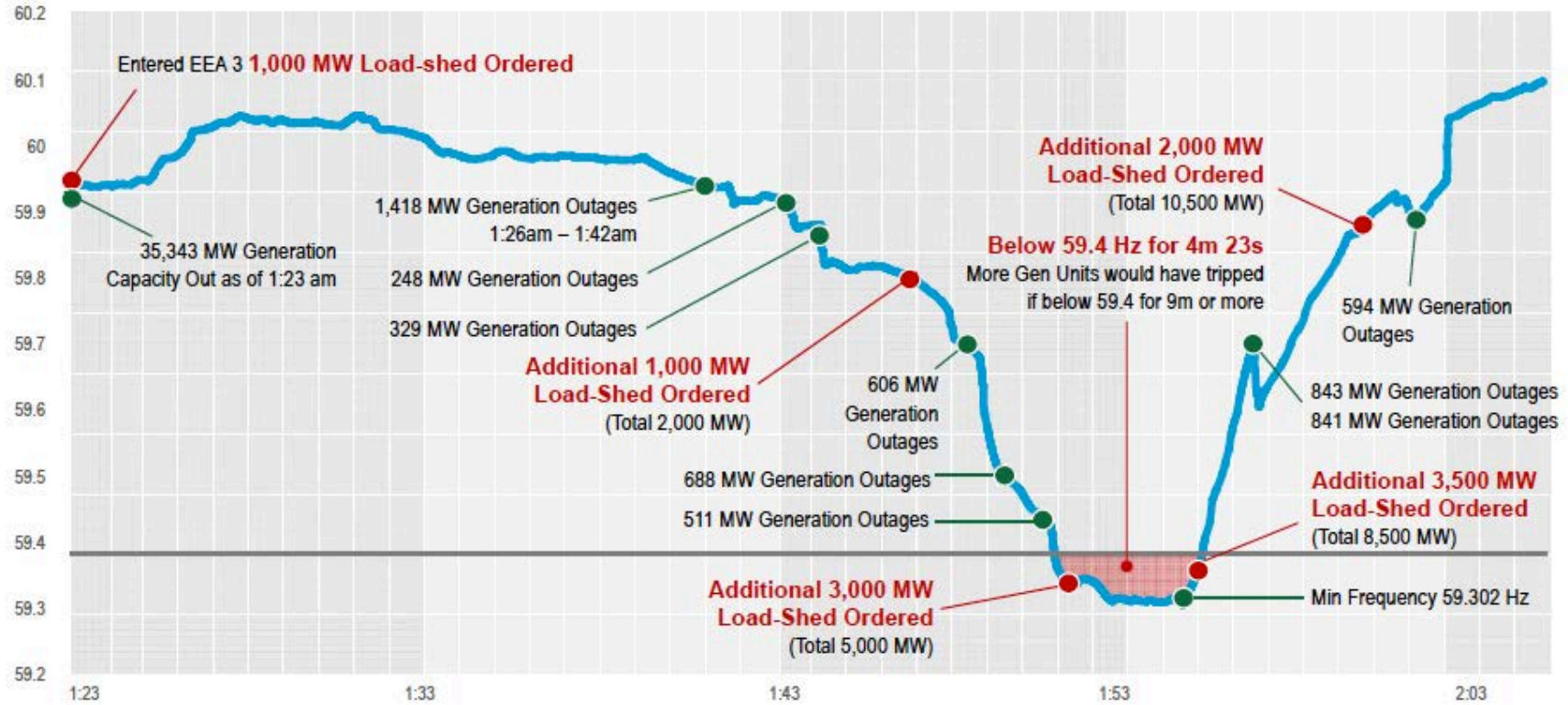
Wind continues to operate

(Although some wind turbines were shut down because of cold conditions, wind generation performed at near-forecast levels on an hour-ahead basis.)

https://www.eia.gov/beta/electricity/gridmonitor/dashboard/electric_overview/balancing_authority/ERCO

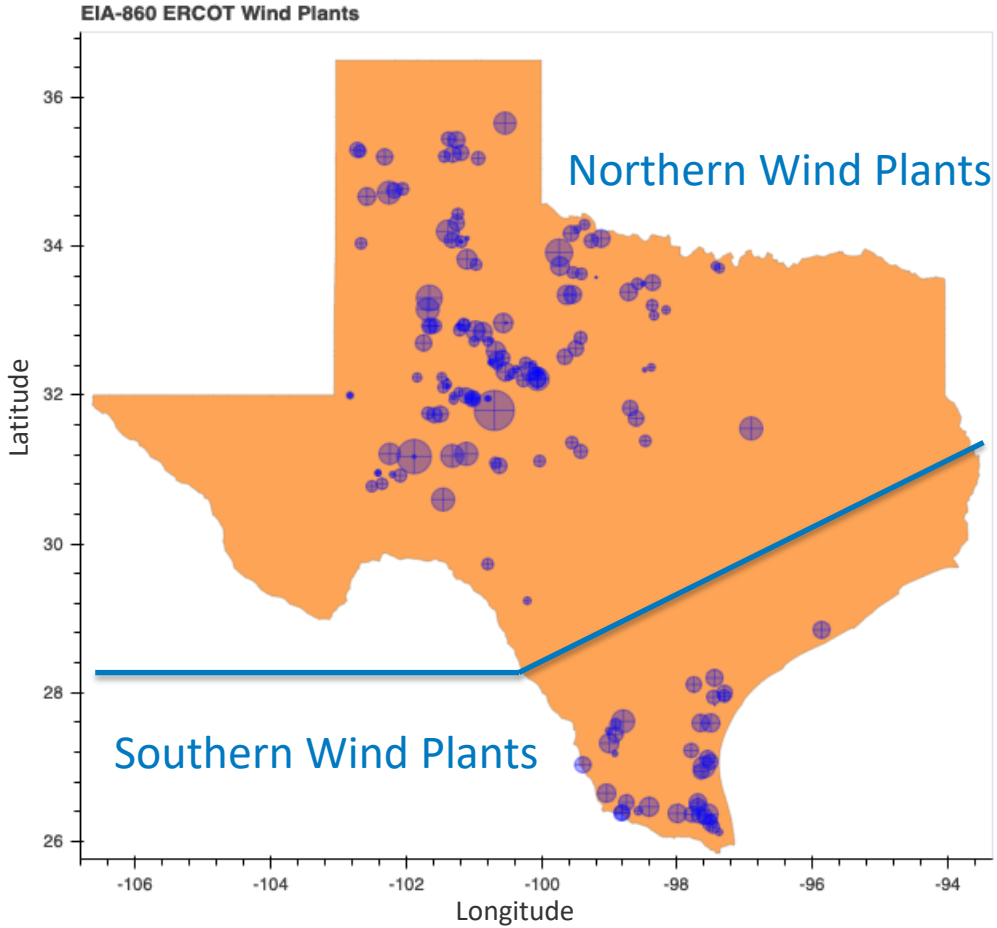
A Rapid Decrease in Power Generation Causes a Frequency Drop

ERCOT ordered load shedding (red) to keep the system from experiencing an interconnectionwide blackout.



Source: ERCOT Public Briefing, *Review of February 2021 Extreme Cold Weather Event*, ERCOT Presentation, February 24, 2021

A Closer Look at Wind Generation



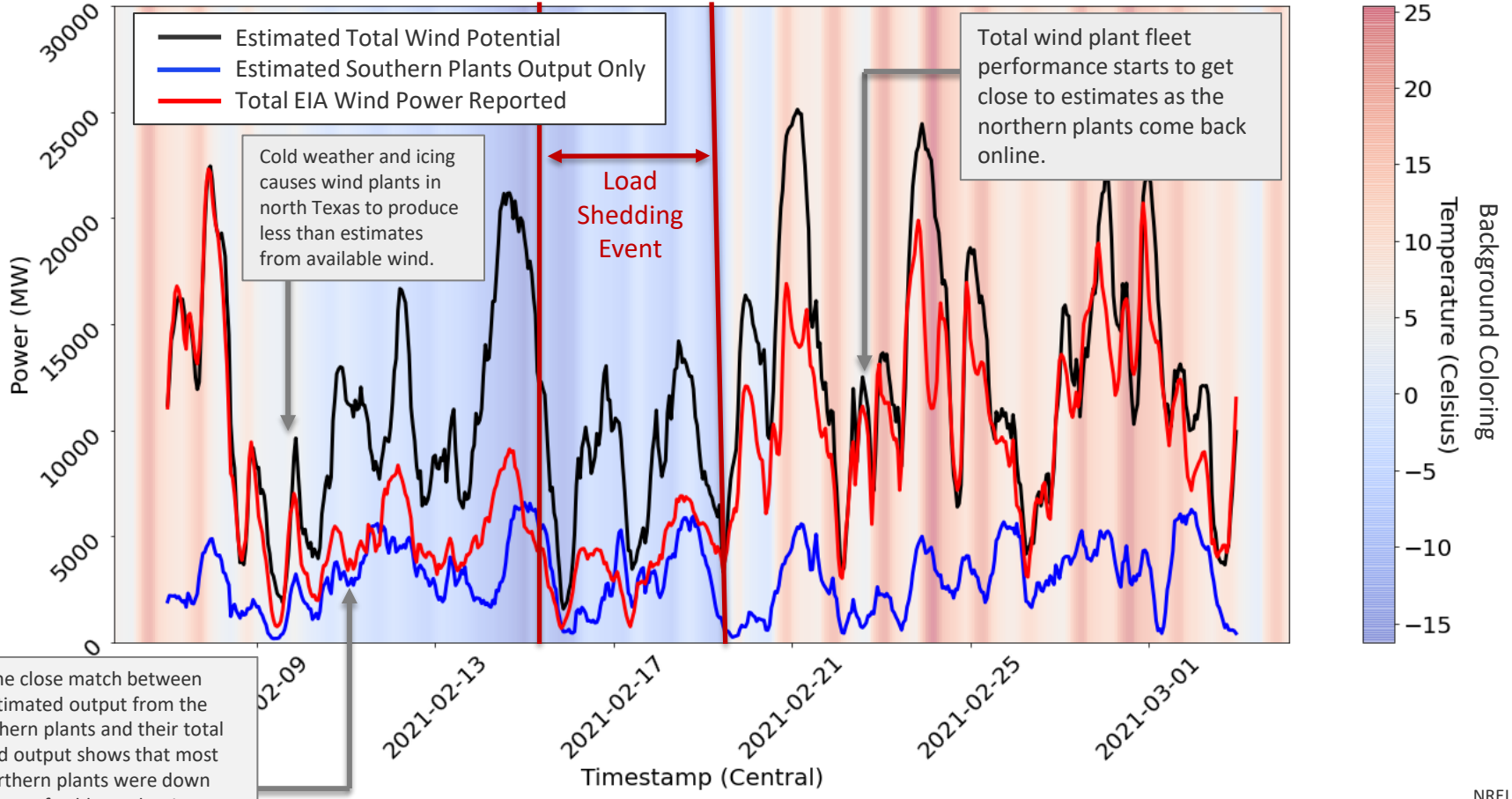
To examine the impact of cold weather on wind energy production, NREL developed an estimate of wind power based on available wind resources for all plants in ERCOT.

The estimates of wind power output at each plant site were calculated using wind speed information and wind plant size and type.

Note that wind plants in ERCOT generally fall into two main areas (north and south).

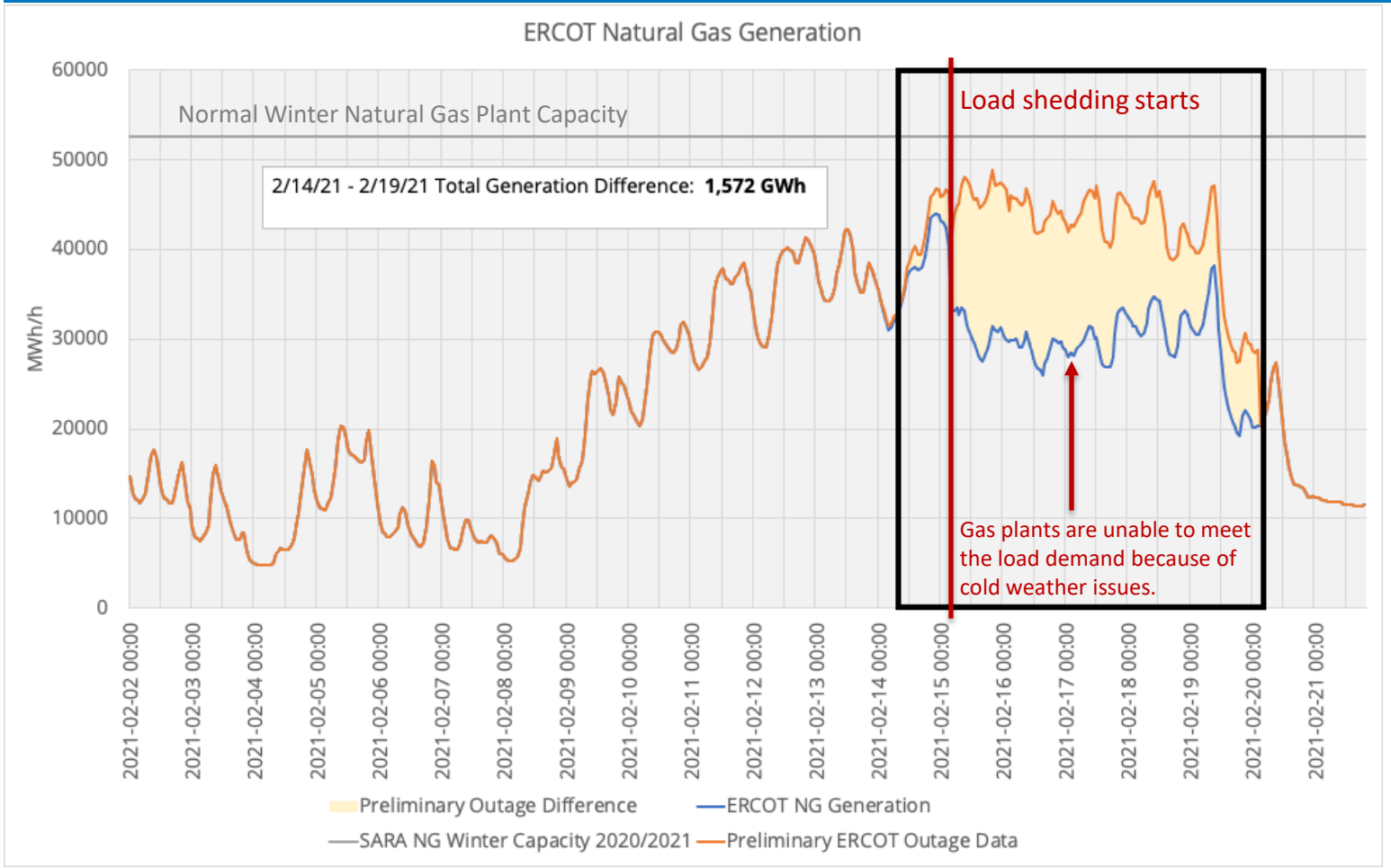
Relative plant size is denoted by the size of the circles in the figure.

Estimated and Reported Wind Plant Power Output (Lines) and Hourly Average Plant Temperature Across All of ERCOT (Background Color)



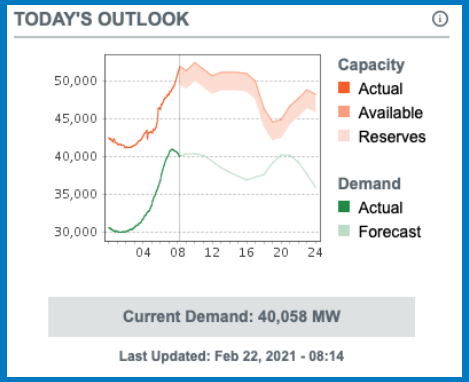
The close match between estimated output from the southern plants and their total wind output shows that most northern plants were down because of cold weather issues.

A Closer Look at Natural Gas Power Generation

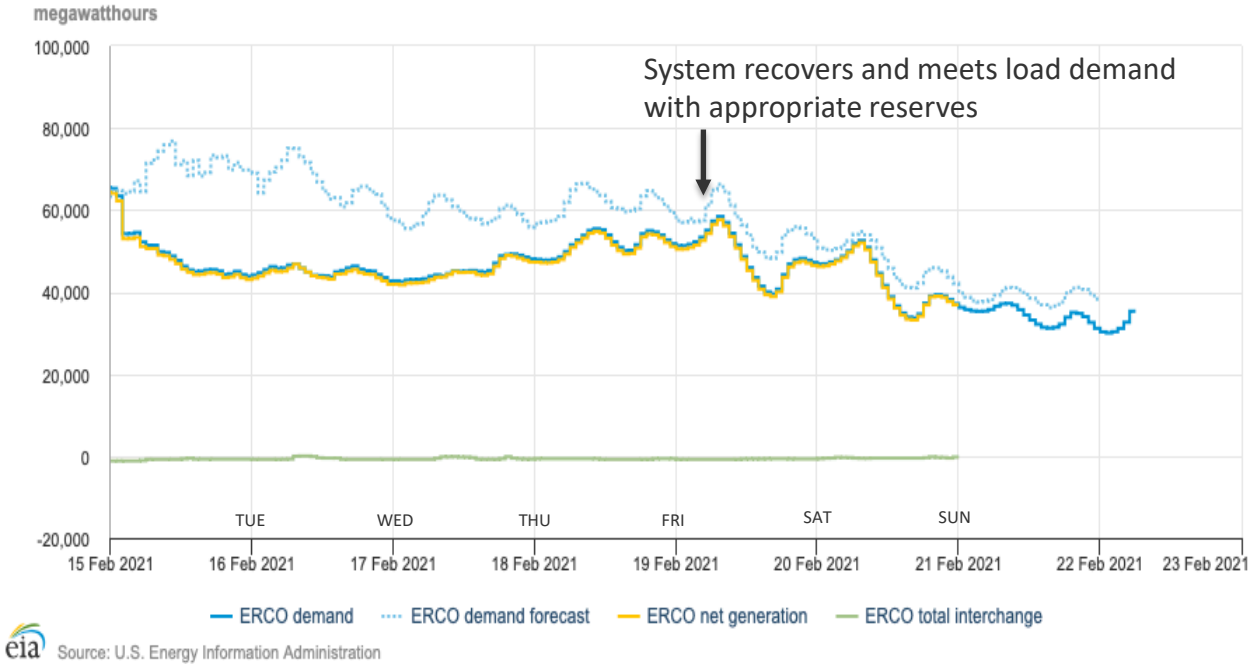


Source: C. Clack, A. Choukulkar, B. Coté, and S. McKee (February 2021) *ERCOT Winter Storm Uri Blackout Analysis*, Vibrant Clean Energy, LLC.

Recovery and Back-to-Normal Operations February 19–22, 2021



Electric Reliability Council of Texas, Inc. (ERCO) electricity overview (demand, forecast demand, net generation, and total interchange) 2/15/2021 – 2/22/2021, Central Time

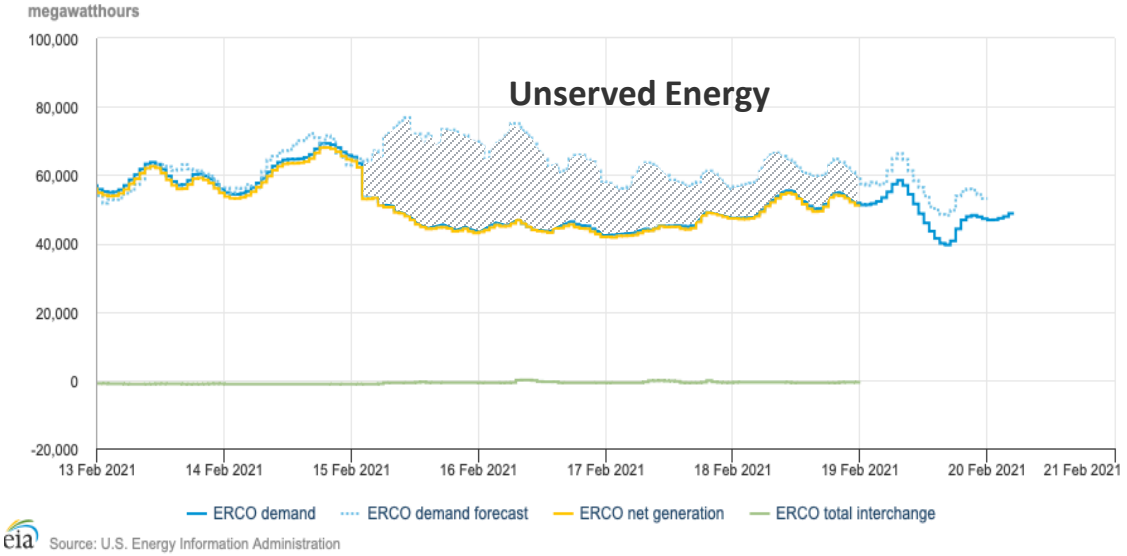


eia Source: U.S. Energy Information Administration

Unserved Energy

- From February 15−18, if ERCOT's demand forecast is 100% accurate, ERCOT recorded an unserved energy around 1,560 GWh over 4 days.
- The peak unserved energy was around 20 GW.
- 26% of the estimated load was curtailed.
- As a comparison point, there is about 23 GW of installed storage in the United States.

Electric Reliability Council of Texas, Inc. (ERCO) electricity overview (demand, forecast demand, net generation, and total interchange) 2/13/2021 – 2/20/2021, Central Time



eia Source: U.S. Energy Information Administration

Load Shedding Ordered by Transmission Owner

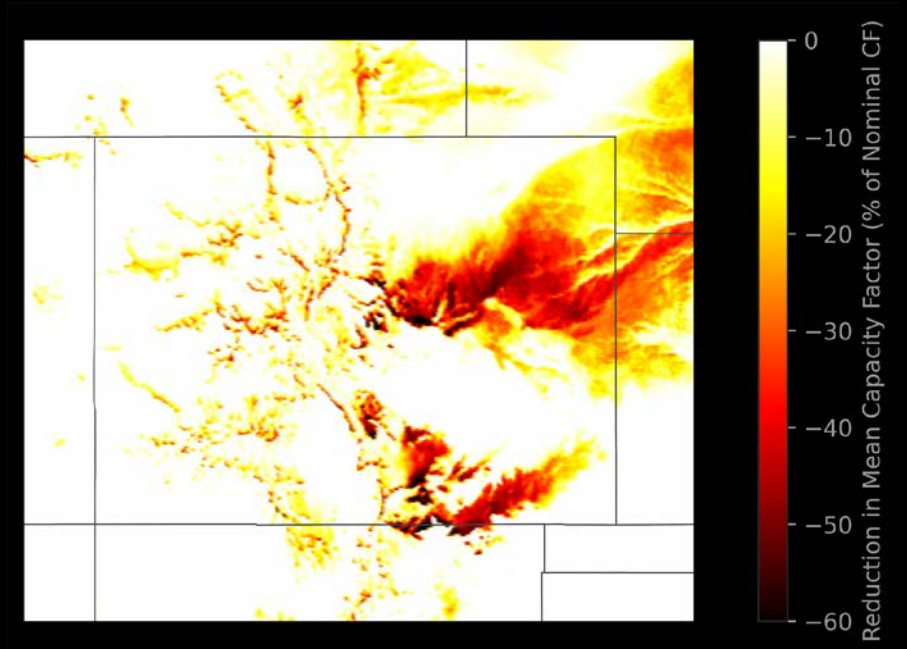
Transmission Operator	% of MW
AEP Texas Central Company	8.7
Brazos Electric Power Cooperative Inc.	4.95
Brownsville Public Utilities Board	0.37
Bryan Texas Utilities	0.51
CenterPoint Energy Houston Electric LLC	24.83
City of Austin DBA Austin Energy	3.71
City of College Station	0.28
City of Garland	0.75
CPS Energy (San Antonio)	6.79
Denton Municipal Electric	0.48
GEUS (Greenville)	0.15
Lamar County Electric Cooperative Inc	0.07
LCRA Transmission Services Corporation	5.96
Oncor Electric Delivery Company LLC	36.01
Rayburn Country Electric Cooperative Inc.	1.3
South Texas Electric Cooperative Inc.	2.52
Texas-New Mexico Power Company	2.62
ERCOT Total	100.00

Source: *ERCOT Public Briefing, Review of February 2021 Extreme Cold Weather Event*, ERCOT Presentation, February 24, 2021

Weather Event Analysis of Future Power Systems

- The Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy has supported extreme weather event analysis of high variable generation systems.
- DOE supported the development and use of the NAERM to analyze the 2014 Northeast Polar Vortex.
- DOE Grid Modernization Laboratory Consortium has conducted research on near-term reliability and resilience.
- NREL's Energy Security and Resilience Center has developed weather resilience metrics.

October 2009 Colorado Icing Event



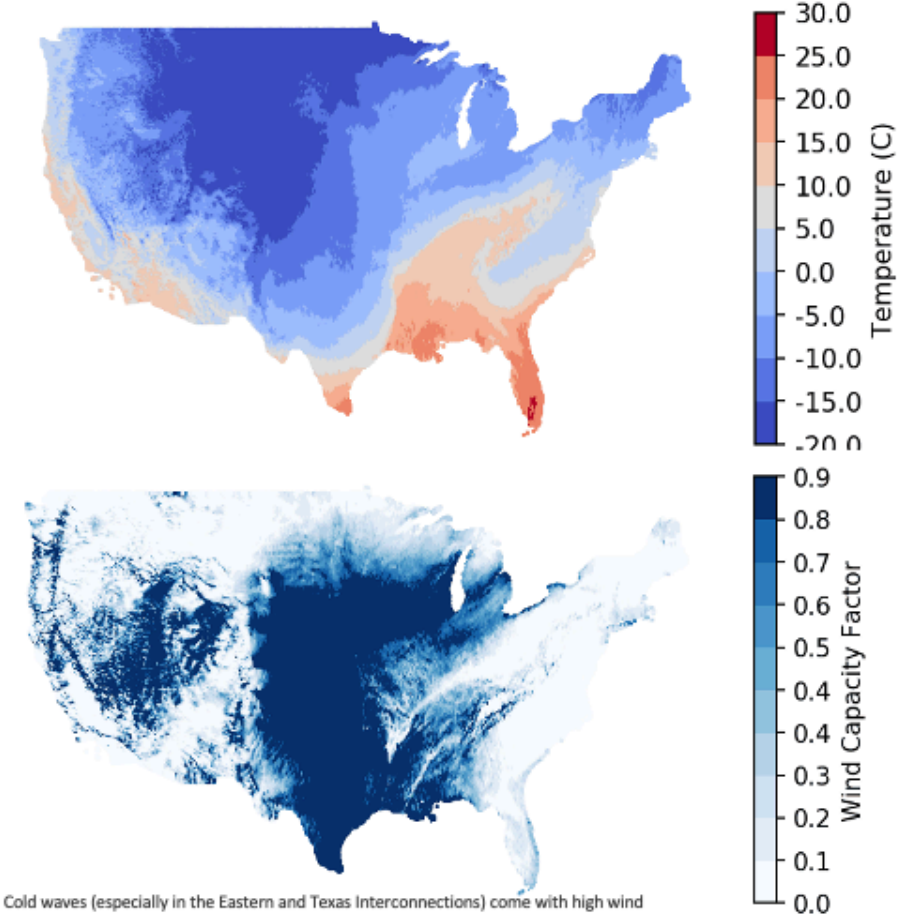
The figure shows the spatial reduction in mean capacity factor for wind generation due to blade icing over the 4-day cold weather event that occurred in October 2009.

Extreme Weather Events: January 2011 Cold Wave

Cold waves (especially in the Eastern and Texas Interconnections) come with high wind resources as cold pushes down the Front Range of the Rocky Mountains.

How widespread and prolonged stagnant wind lasts differs between cold waves.

Example: January 2011 Cold Wave



Cold waves (especially in the Eastern and Texas Interconnections) come with high wind resource as cold pushes down the Front Range of the Rocky Mountains. How widespread and prolonged stagnant wind lasts differs between cold waves.

Summary

The Texas load-shedding events were caused by a combination of record-high demand and cold weather issues that reduced the output from all types of generation.

While some wind turbines were shutting down due to cold temperatures and icing and a lack of cold-weather packages, hourly wind output was accurately predicted.

Extreme weather events historically drive grid reliability. Additional examination of more extreme events is needed to understand their impacts on the power system.

As a national lab, NREL has the capabilities and facilities to help the industry address these types of challenges.

NREL also has significant simulation and analysis capabilities (such as NAERM) that can help understand the impacts of extreme events.

NREL also developed the Advanced Research on Integrated Energy Systems (ARIES) Research Platform, which enables evaluation of technologies that smooth grid operations during events like this.

Thank You

www.nrel.gov

NREL/PR-5000-80071