Lessons from the 2021 Texas Electricity Crisis

Peter Cramton

5 July 2021, latest version

Peter Cramton is Professor of Economics at the University of Cologne and the University of Maryland (emeritus since 2018). He was an independent director of the ERCOT board from 2015-2021. He is grateful to his research team: Emmanuele Bobbio, David Malec, and Pat Sujarittanonta.

Many interconnected systems

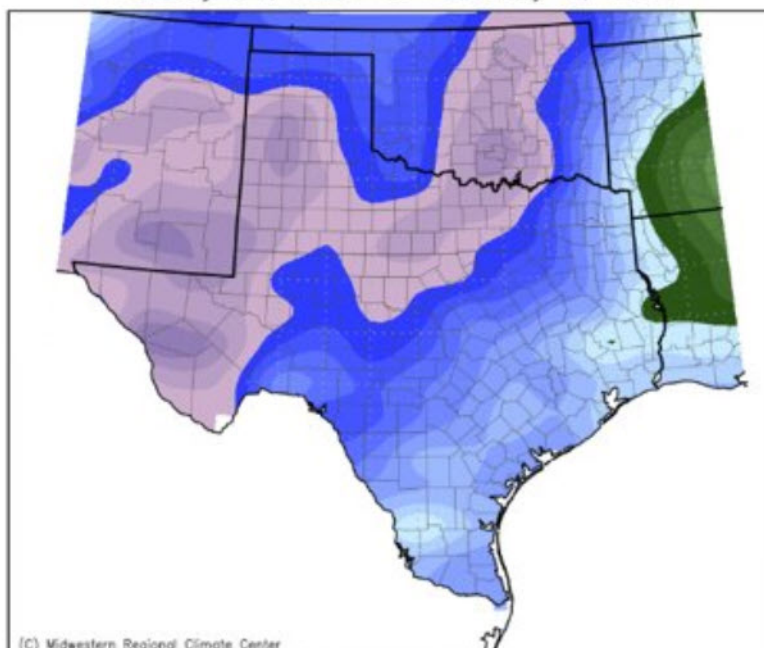Weather

People

Electricity

Water

Gas

Historical Comparison with Past Arctic Outbreaks, 7-day Temperature Anomalies

Temperature departures from normal for the 7-days centered on the coldest day for Dec. 1989, Feb. 2011, and Feb. 2021 outbreaks. Feb. 12-18, 2021 had the most significant extended period of below normal temperatures compared to these prior outbreaks. (Midwest Regional Climate Center online plotter does not go below -25F departure)

Average Temperature (°F): Departure from Mean
December 19, 1989 to December 25, 1989
(C) Midwestern Regional Climate Center
Mean period is 1981-2010.
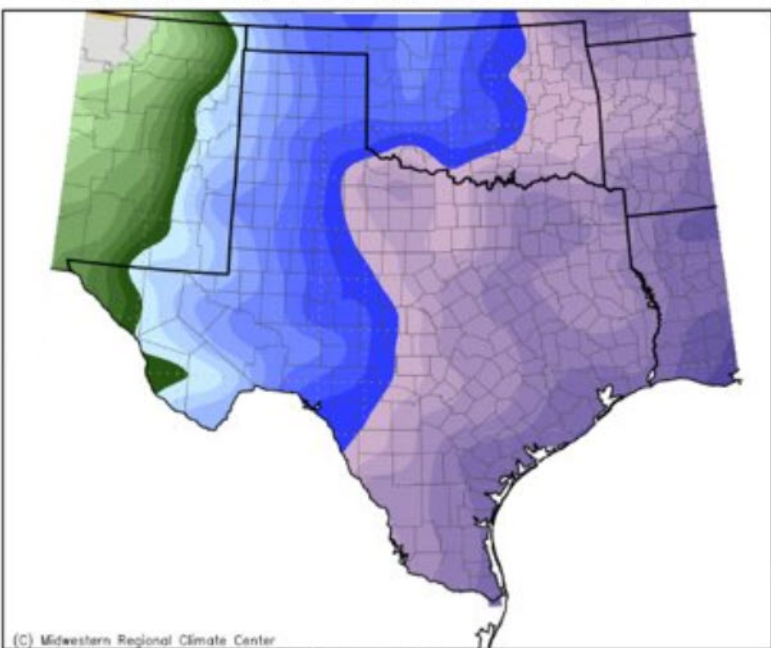
Average Temperature (°F): Departure from Mean
January 31, 2011 to February 6, 2011
(C) Midwestern Regional Climate Center
Mean period is 1981-2010.

Average Temperature (°F): Departure from Mean
February 12, 2021 to February 18, 2021
(C) Midwestern Regional Climate Center
Mean period is 1981-2010.

-25   -20   -15   -10   -5   0

7-day Average Temperature Anomaly (F)
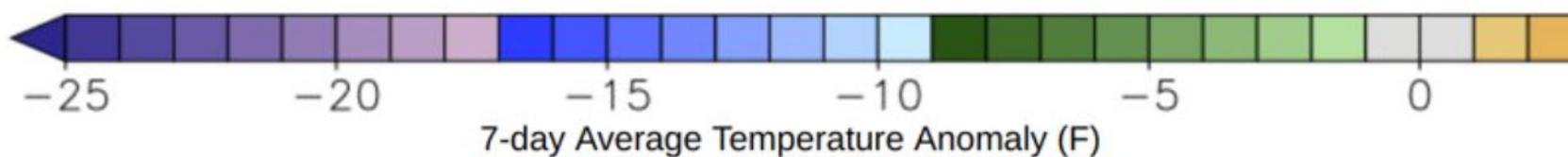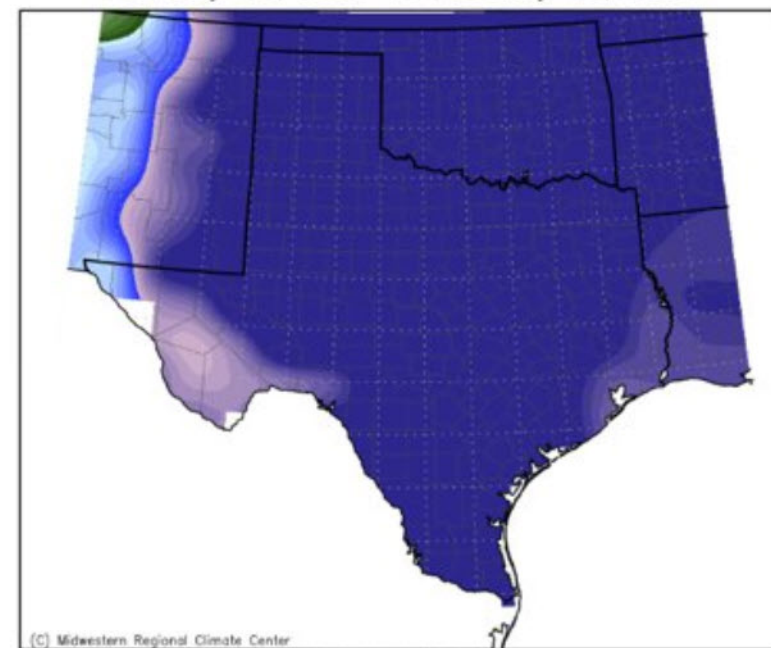
Coldest temperatures during Texas cold snaps, Fahrenheit

ERCOT extreme winter
18.3˚ average
Feb 2011

5.5˚ average
without
Feb 2011

Dallas   Austin   San Antonio   Houston

Natural gas flow drops sharply on Friday, 12 Feb, *well before* electricity outages on Monday, 15 Feb

Texas Natural Gas Flow Data

Source | Enverus
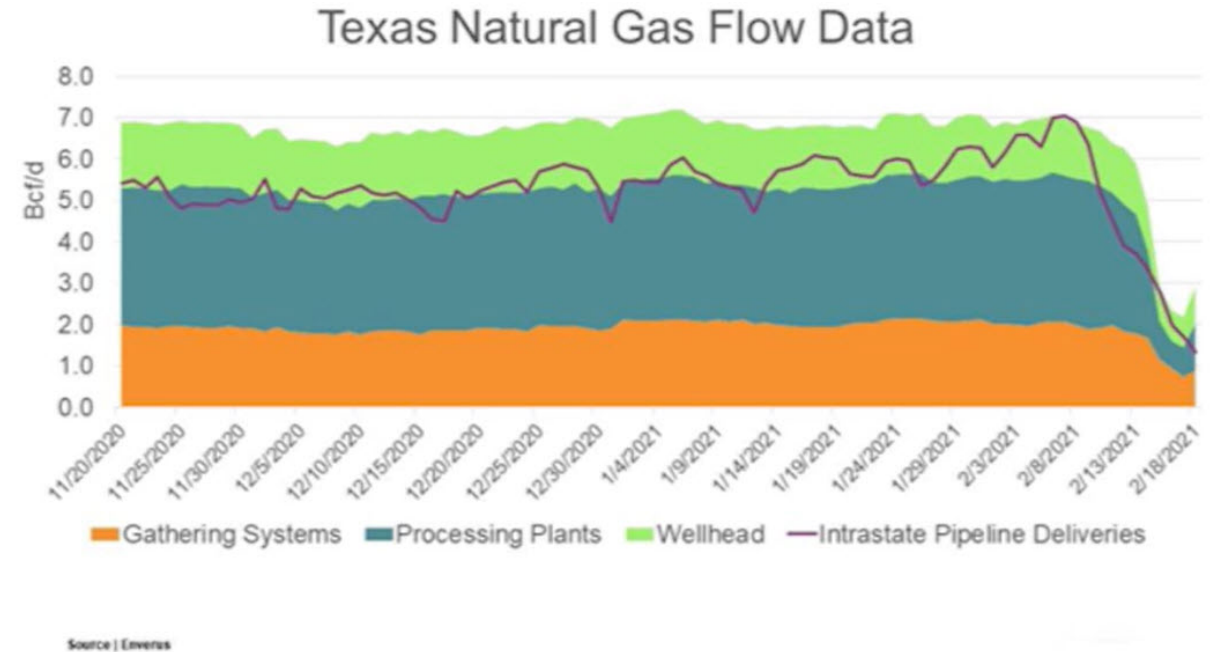
Fri. 12 Feb. 2021

Over the week natural gas pipeline flow data shows a significant drop. Spot gas prices soars on Friday to over $150/MMBtu at HSC (some locations topped out at $999 for other locations according to NGI).

Sat. 13 Feb. 2021 08:43

ERCOT Physical Responsive Capability (PRC), which is a measure of online capacity that is available to respond quickly to disturbances, falls below 3 GW for the first time during the weekend.

ERCOT notes the first major thermal generator failure at 04:02. Frequency declines to 59.238 Hz, while load was at 55,391 MW.

Sat. 13 Feb. 2021 04:02

ERCOT issued a Watch for a projected reserve capacity shortage with no market solution available for HE 17:00-21:00, which causes a high risk for an EEA event.

Sun. 14 Feb. 2021

Source: Enverus, 18 Feb 2021.

TOTAL U.S. DRY GAS PRODUCTION
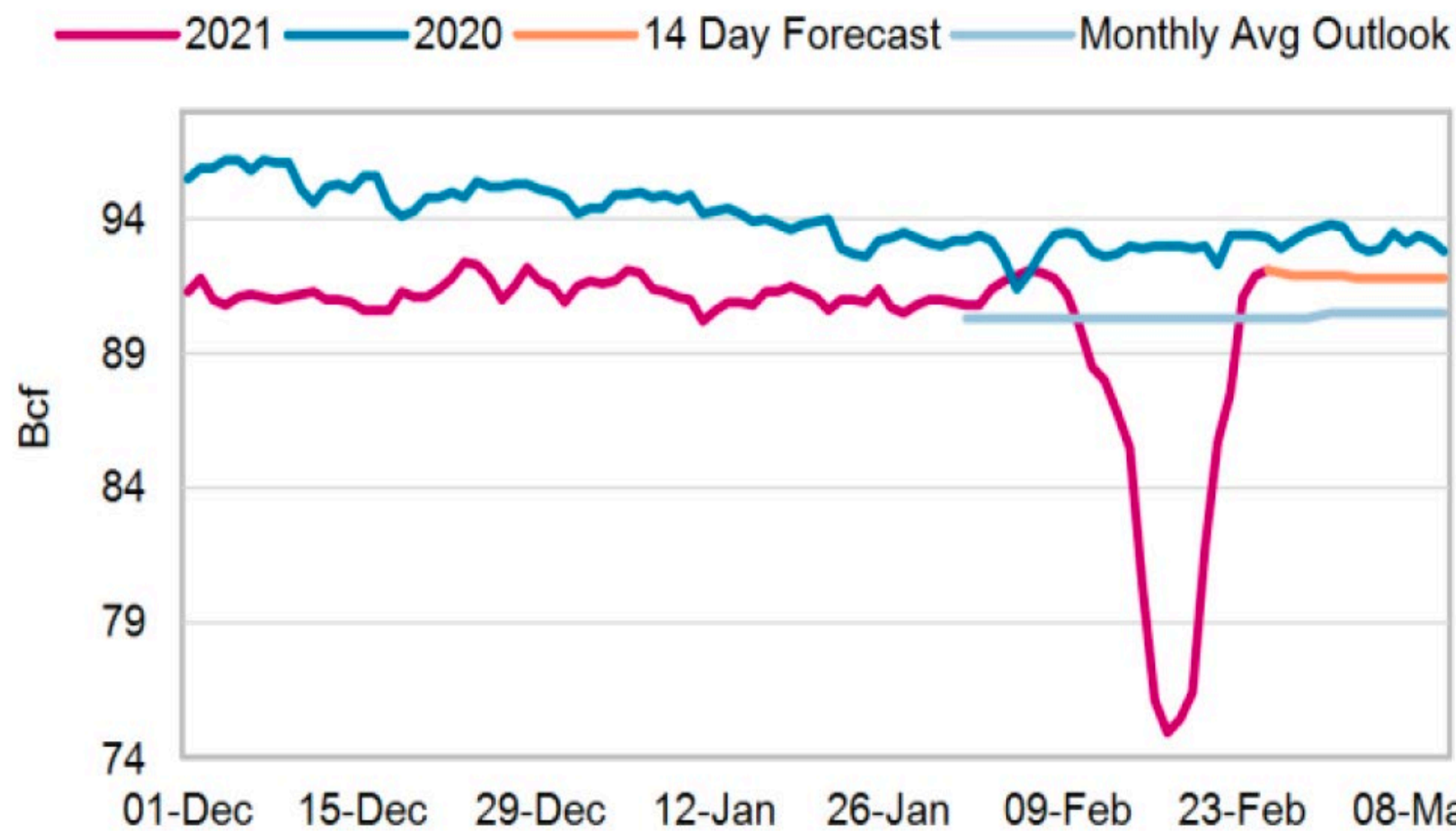
- US natural gas production drops 21%

- TX natural gas production drops 45%

S&P Global Platts

6

Natural gas prices on February 16

Opal: $128

Cheyenne $96

Ventura: $176

Chicago CGT: $146

SoCal CGT: $113

Panhandle: $132

OGT: $919

Waha: $219

Katy: $352

Henry: $17

Gas generators are heavily exposed to gas spot market
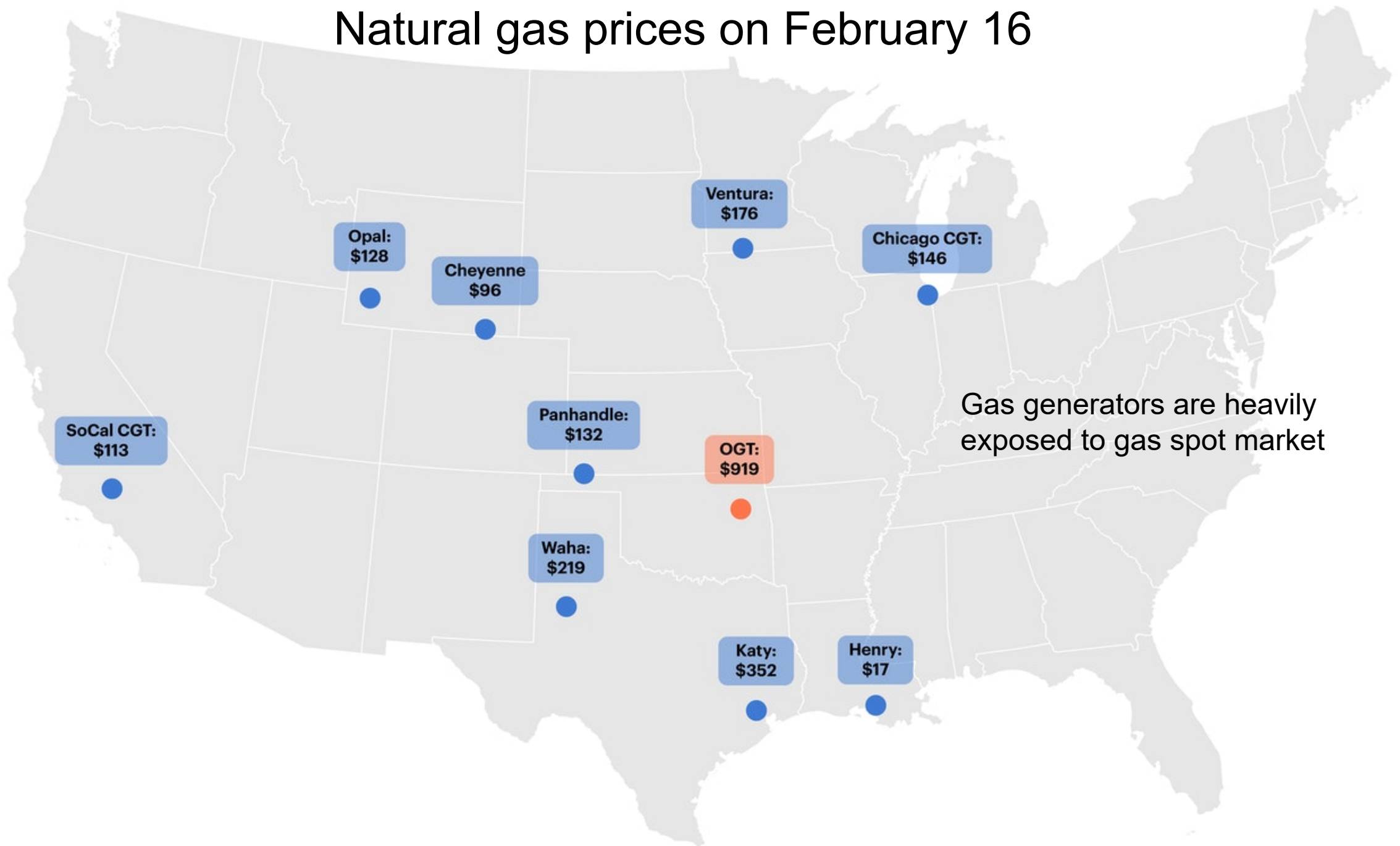
Barnett Shale Gas Production Loss: Freezing Temperature

□ Events not Captured in ERCOT Database, 1994-2009
● Events Captured in ERCOT Database (Deliverable 1), 2002-2011
△ Dec 19-29, 1983 Event projected along loss curve
◇ Dec 11-28, 1989 Event projected along loss curve

$y = -6E-06x^3 + 0.0008x^2 - 0.0293x + 0.4118$
$R^2 = 0.74$

$y = -0.0036x + 0.18$
$R^2 = 0.5264$

Expected Production Loss (%)
Physical Low T(F)
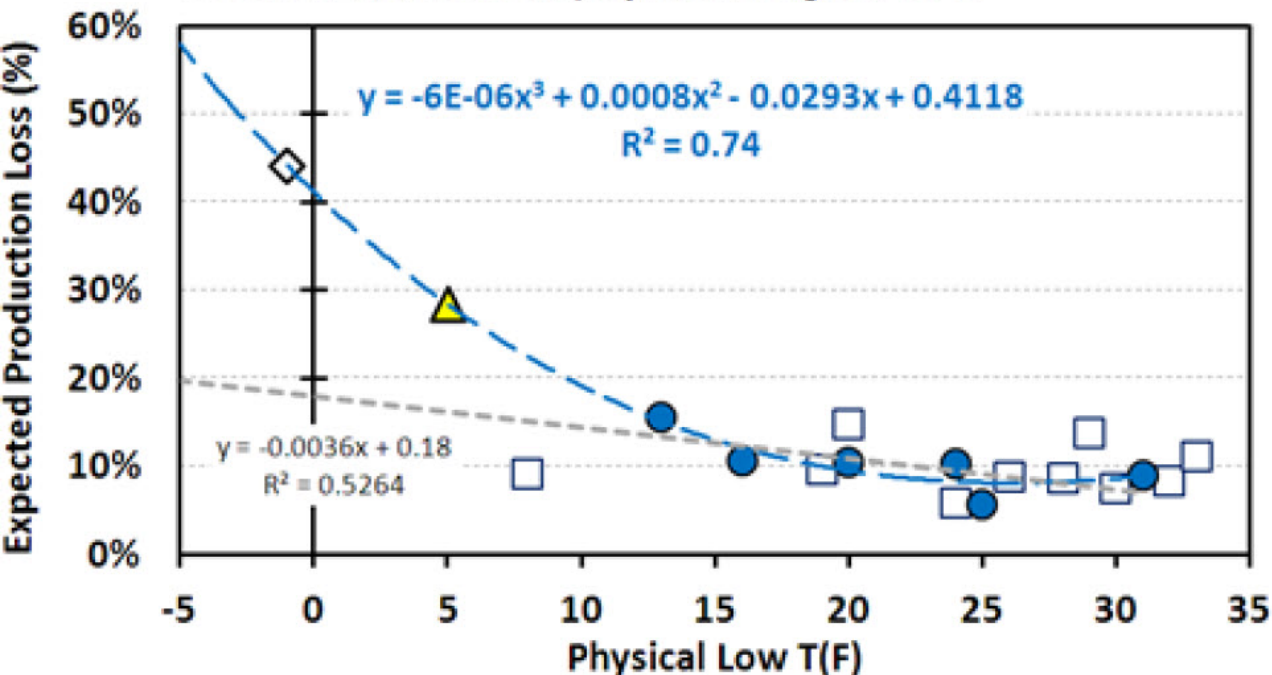
Barnett Shale Gas Production Loss: Wind Chill

□ Events not Captured in ERCOT Database, 1994-2009
● Events Captured in ERCOT Database (Deliverable 1), 2002-2011
△ Dec 19-29, 1983 Event projected along loss curve
◇ Dec 11-28, 1989 Event projected along loss curve

$y = 0.0001x^2 - 0.0055x + 0.1405$
$R^2 = 0.827$

$y = -0.0025x + 0.1338$
$R^2 = 0.6635$

Expected Production Loss (%)
Extreme Windchill T(F)

8

Source: Black & Veatch report for ERCOT, October 2013

LMP Contour Map: Real-Time Market - Locational Marginal Pricing
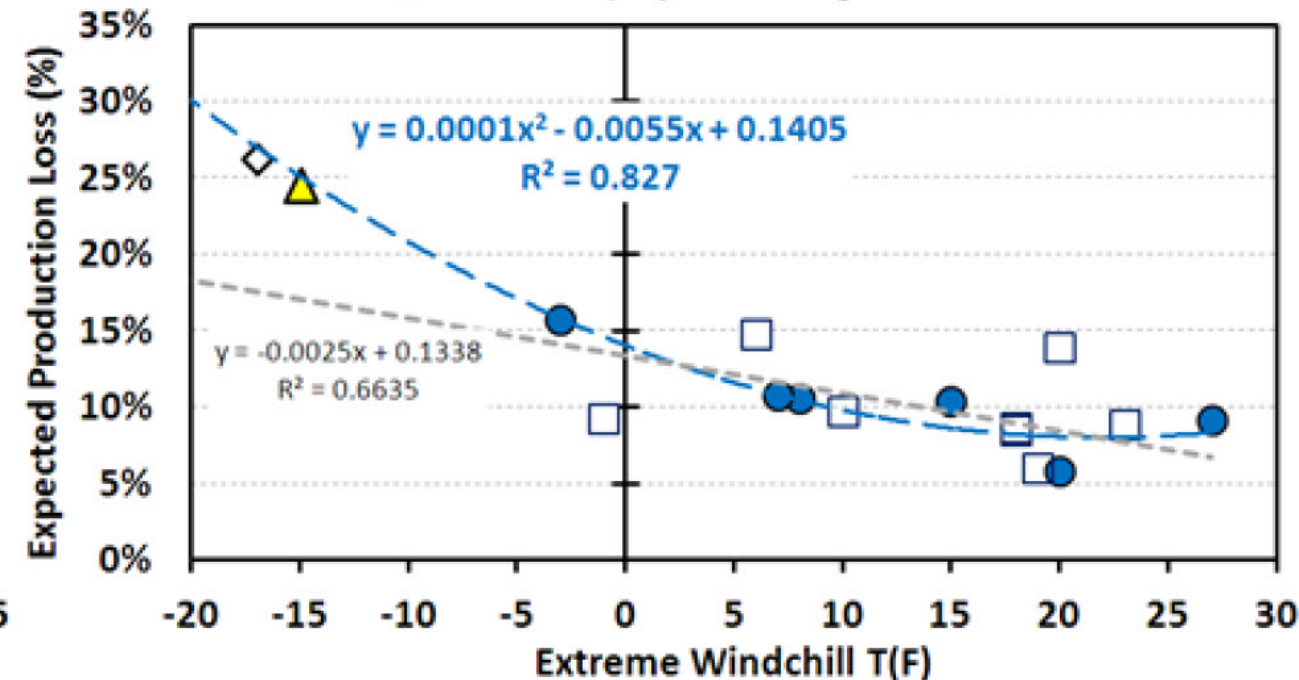
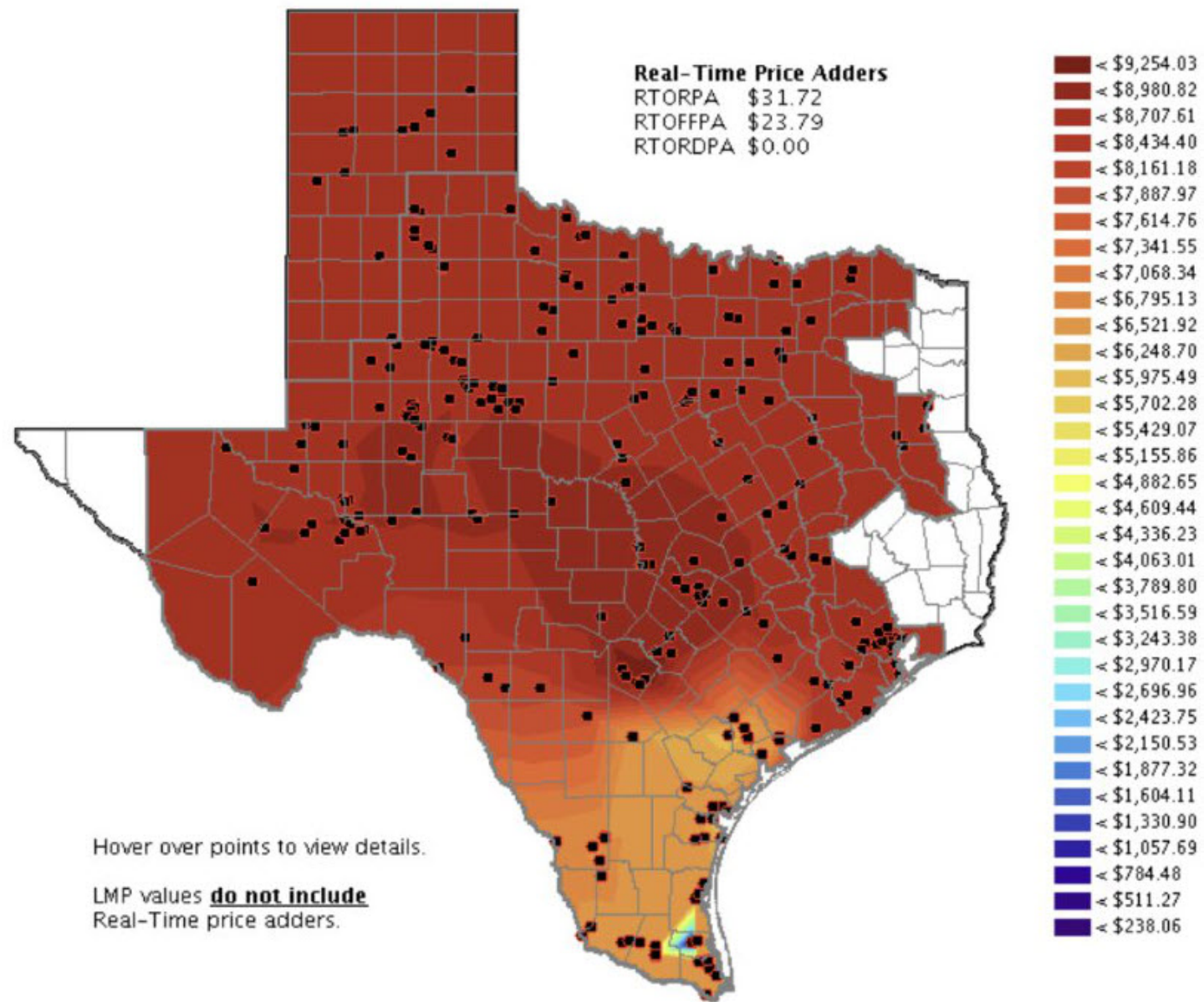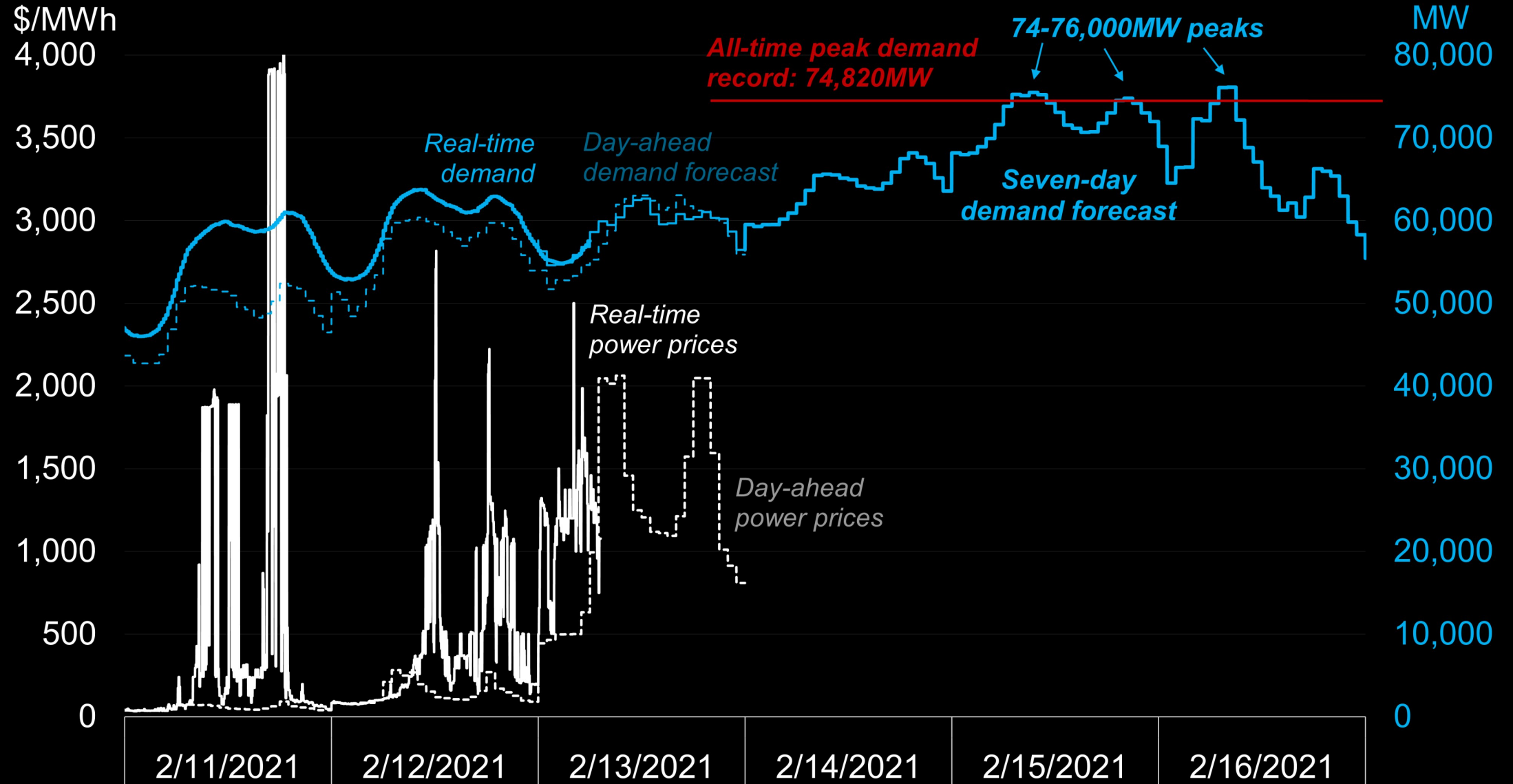Last Updated: Feb 13, 2021 09:10   Download KML: Contours and Points / Points Only / TX Counties / ERCOT Region

Real-Time Price Adders
RTORPA $31.72
RTOFFPA $23.79
RTORDPA $0.00

Hover over points to view details.

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

< $9,254.03	
< $8,980.82	
< $8,707.61	
< $8,434.40	
< $8,161.18	
< $7,887.97	
< $7,614.76	
< $7,341.55	
< $7,068.34	
< $6,795.13	
< $6,521.92	
< $6,248.70	
< $5,975.49	
< $5,702.28	
< $5,429.07	
< $5,155.86	
< $4,882.65	
< $4,609.44	
< $4,336.23	
< $4,063.01	
< $3,789.80	
< $3,516.59	
< $3,243.38	
< $2,970.17	
< $2,696.96	
< $2,423.75	
< $2,150.53	
< $1,877.32	
< $1,604.11	
< $1,330.90	
< $1,057.69	
< $784.48	
< $511.27	
< $238.06	

Select Data RTM-LMP ▾   View As High Gradient ▾

9

Extreme Cold Could Push Texas Electricity Demand to All-time Highs

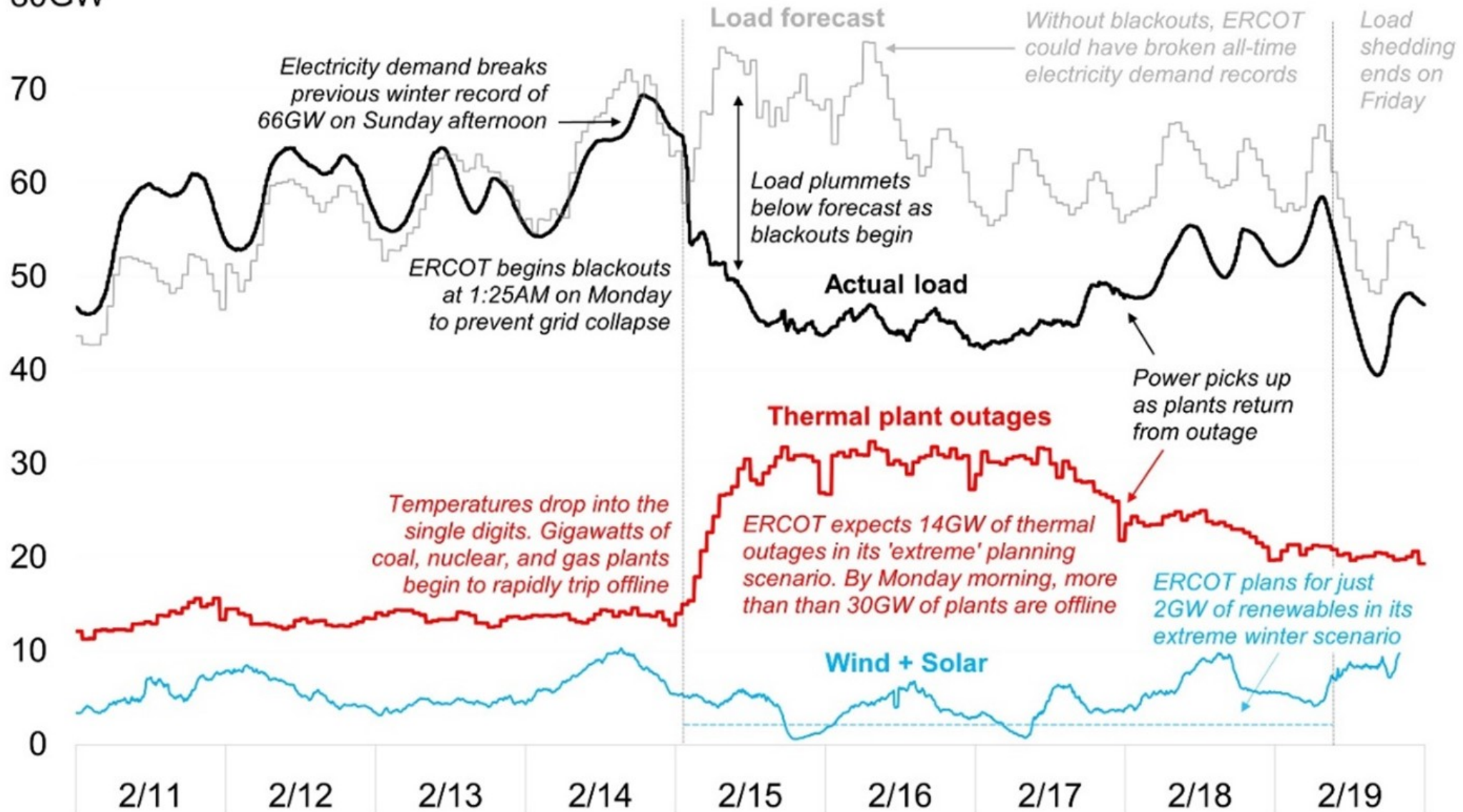ERCOT load and power prices

Source: ERCOT

Note: As of February 13, 8am EST

Source: Brian Bartholomew

Extreme Weather, Extreme Outages Pushed Texas into Blackouts

ERCOT electric load, load forecasts, thermal plant outages, and renewables
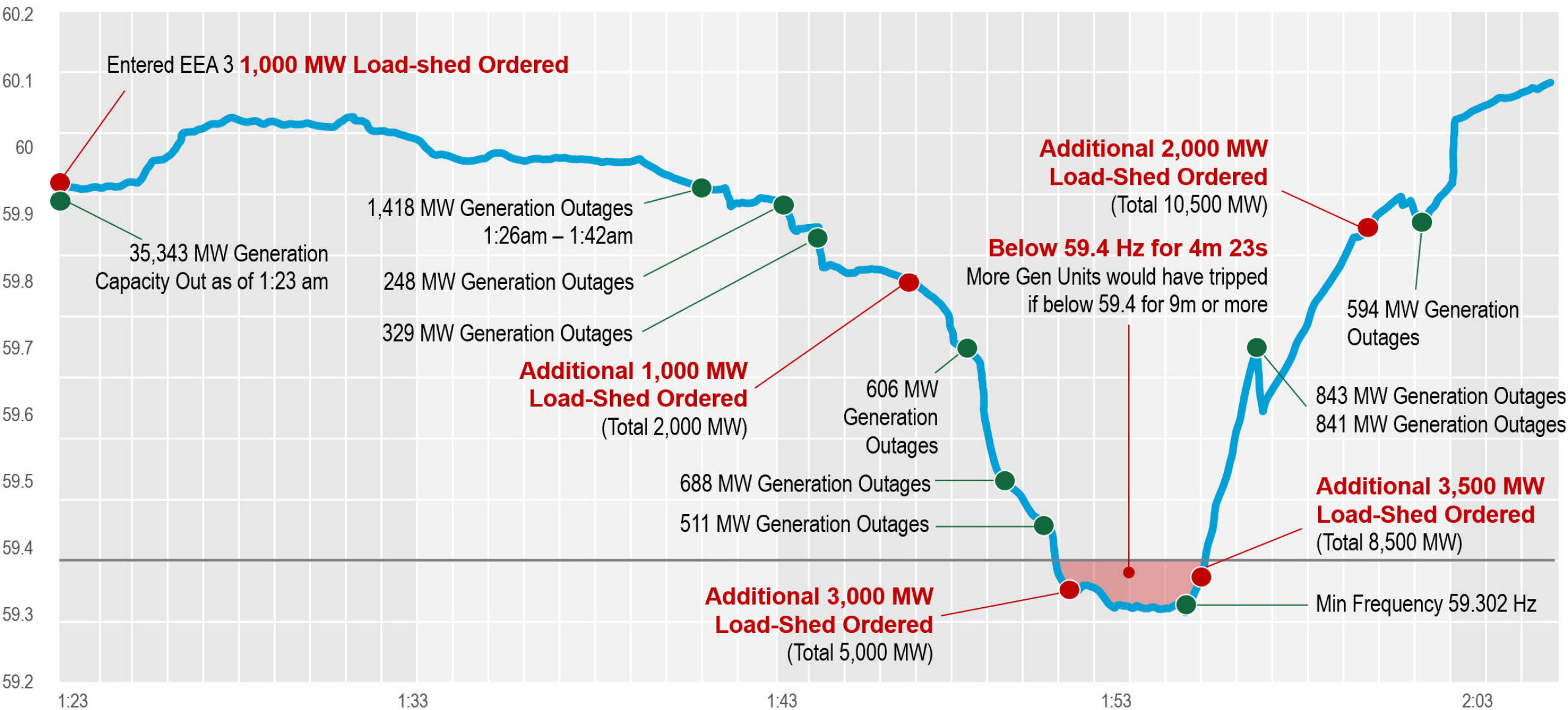

80GW

Load forecast

Electricity demand breaks previous winter record of 66GW on Sunday afternoon

Without blackouts, ERCOT could have broken all-time electricity demand records

Load shedding ends on Friday

Load plummets below forecast as blackouts begin

ERCOT begins blackouts at 1:25AM on Monday to prevent grid collapse

Actual load

Power picks up as plants return from outage

Thermal plant outages

Temperatures drop into the single digits. Gigawatts of coal, nuclear, and gas plants begin to rapidly trip offline

ERCOT expects 14GW of thermal outages in its 'extreme' planning scenario. By Monday morning, more than than 30GW of plants are offline

ERCOT plans for just 2GW of renewables in its extreme winter scenario
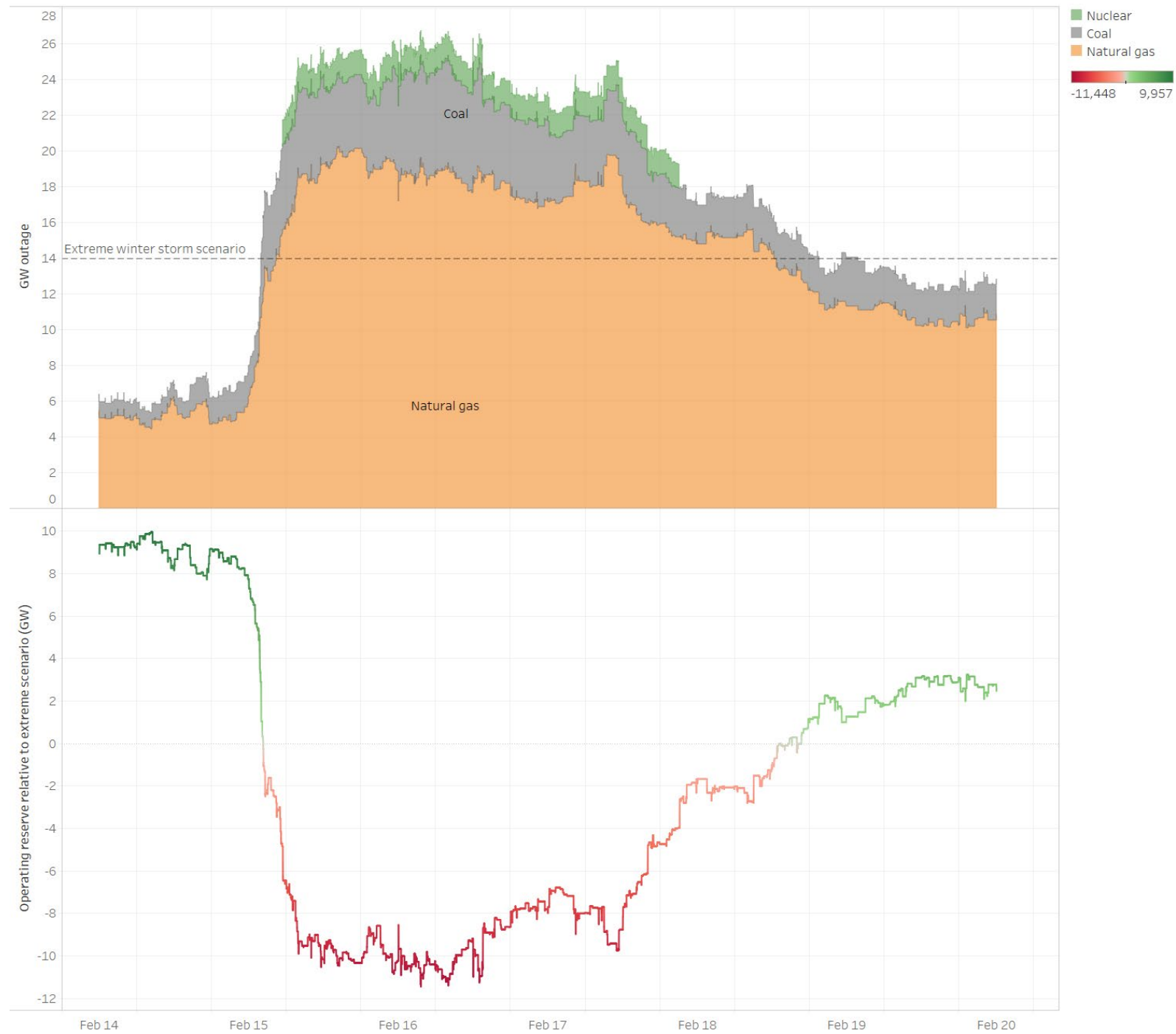
Wind + Solar

Data source: ERCOT   *Note: 'Thermal plant outages' is non-renewable generator outages reported by ERCOT*

11

Source: Brian Bartholomew

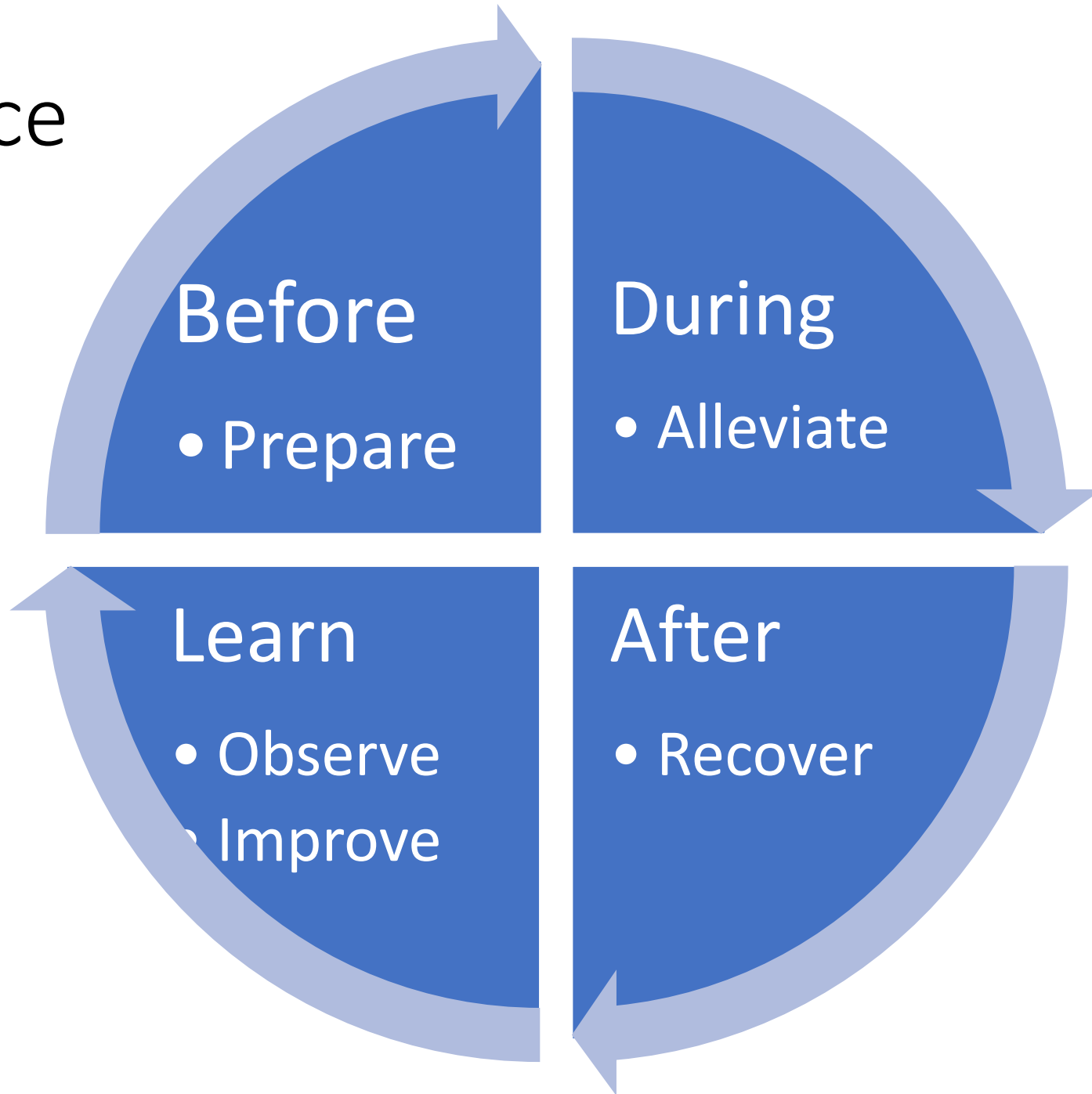ERCOT control room 1 am, Monday, February 15

Entered EEA 3 **1,000 MW Load-shed Ordered**

35,343 MW Generation Capacity Out as of 1:23 am

1,418 MW Generation Outages 1:26am – 1:42am

248 MW Generation Outages

329 MW Generation Outages

Additional 1,000 MW Load-Shed Ordered (Total 2,000 MW)

606 MW Generation Outages

688 MW Generation Outages

511 MW Generation Outages

Additional 3,000 MW Load-Shed Ordered (Total 5,000 MW)

Additional 2,000 MW Load-Shed Ordered (Total 10,500 MW)

Below 59.4 Hz for 4m 23s More Gen Units would have tripped if below 59.4 for 9m or more

594 MW Generation Outages

843 MW Generation Outages 841 MW Generation Outages

Additional 3,500 MW Load-Shed Ordered (Total 8,500 MW)

Min Frequency 59.302 Hz

Thermal outages

Legend:
- Nuclear
- Coal
- Natural gas

Color scale: -11,448 to 9,957

Top chart (GW outage): Coal, Natural gas, Extreme winter storm scenario (dashed line at ~14 GW)

Bottom chart: Operating reserve relative to extreme scenario (GW)

X-axis: Feb 14, Feb 15, Feb 16, Feb 17, Feb 18, Feb 19, Feb 20

13

Resilience

Before
- Prepare

During
- Alleviate

Learn
- Observe
- Improve

After
- Recover

Improve communications

Governor and regulator

System operator

Public

Generators

Distribution companies

Retail service providers

Customers

It is likely that many Texans will lose power because of the storm, some for multiple days. The number of Texans who must experience a long outage in freezing temperatures depends on your actions. I ask and plead with all Texans who have power: *Please put your sweaters and coats on and turn the thermostat down to 55˚ F or lower*. Each kilowatt-hour you conserve enables more Texans to have power. Let's stand together and defeat this storm.

Improve critical infrastructures essential for a resilient grid

Reform the natural gas market to assure a reliable supply of gas in sub-zero temperatures
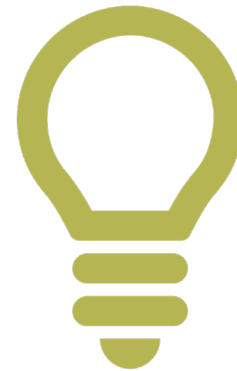
Use standards and grants to promote energy efficiency in new and existing homes

Electricity market design matters

First fix your spot market

Financial day ahead market for scheduling

- Co-optimize energy & reserves to maximize as-bid social welfare subject to constraints
- Allow simple expression of unit characteristics and economics (3-part bids for fossil)
- Allow virtual bids and offers to arbitrage between day ahead and real time markets
- Automatically mitigate market power if it appears due to local constraints

Physical real time market for dispatch and settlement

- Co-optimize energy & reserves to maximize as-bid social welfare subject to constraints
- Automatically mitigate market power if it appears due to local constraints

Result: Day-ahead and real-time prices that induce efficient behavior!

Improve ERCOT market rules and systems to embrace the future

Improve forecasting

Improve the analysis of resilience and reliability

Encourage price-responsive demand

Integrate battery storage

Accommodate distributed generation

Add a winter circuit breaker

Avoid repricing, especially of forward markets

Facilitate liquid and efficient trade of forward energy

Add a forward-energy market for simple, transparent, and efficient trade up to 48 months ahead

Consider a 24-hour rolling settlement that is more flexible and efficient than the day-ahead market

Improve the real-time market with a 60-minute rolling look ahead

Is reliability a public good?

Absent demand response, yes.

But an effective market encourages demand response with

- Demand curves for reserves that reflect the value of avoiding shortage ($9000 shortage price)
- Rate plans that let the consumer see and feel the real-time price on the margin (it is fine if most consumers select a flat rate plan!)
- Emergency demand response that pays customers to reduce in emergency
  - ERCOT has 2 GW
  - Pay-for-performance is key (e.g., ERCOT Aug 2019 vs CA Aug 2020)

Result: reliability is no longer a problem (and is not a public good)

Capacity market: Buy enough in advance

- Buy: capacity is bought on behalf of load

  - Capacity = energy and reserves during shortage [vs anytime]

  - Capacity is a derivative of the real time market = *pay for performance* [vs exceptions, missing money]
- Enough:

  - Capacity demand curve to guarantee physical capability [vs vertical]

  - Capacity value = ability to provide energy during shortage [vs nameplate, EFORd]
- In advance:

  - Three years ahead for price formation [vs spot]

Learning to ride a bike: does a capacity market help or hurt?

$125

$55

Forward energy market

- Simple, transparent, and efficient trade up to 48-months ahead

- Single foundational product: monthly forward energy by months ahead, hour of day, weekday or weekend, load zone (2 x 24 x 48 = 2304 products per zone, e.g. August 2022, 5 pm, weekday, Houston)

- Preferences: Each participant submits a piecewise linear demand curves for one or more linear combination of products (shifting from current position to a new target position) in quantity flows expressing the rate at which you move to new position based on prices (Budish-Cramton-Kyle-Lee-Malec, "Flow Trading")

Climate policy matters

Power sector CO2 emissions

Global energy related CO2 emissions, 1990-2019
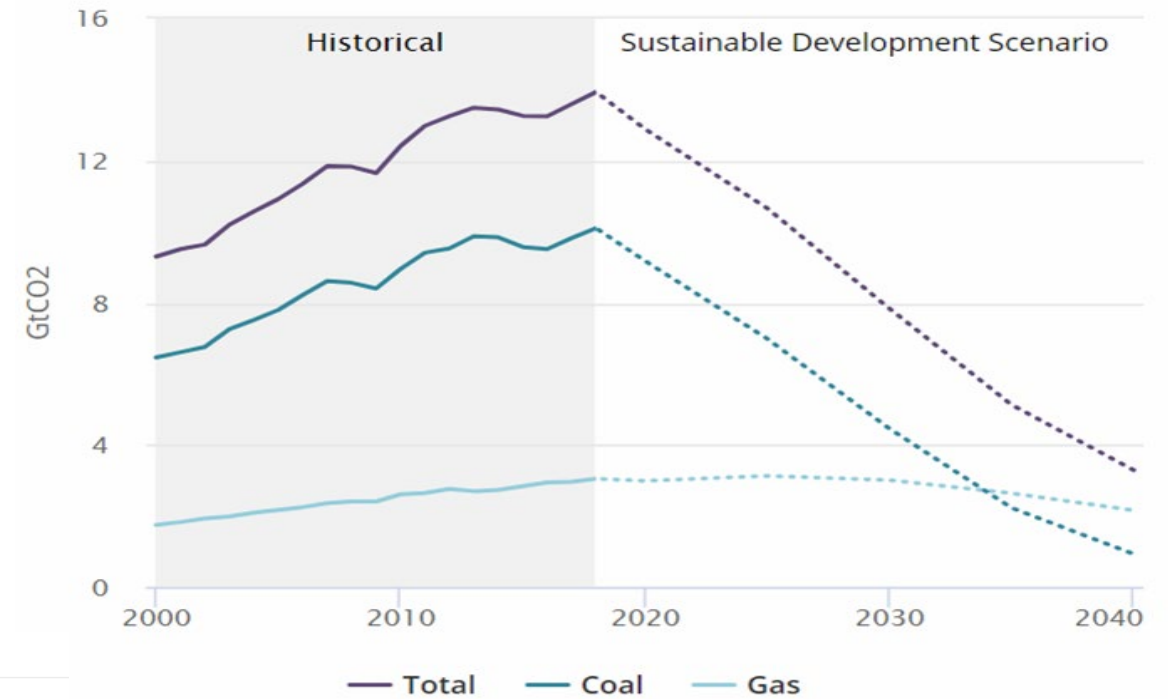
Last updated Tuesday, May 28, 2019

Electricity Markets in Transition

A forty-year model of entry and exit

Peter Cramton, Emmanuele Bobbio,
David Malec and Pat Sujarittanonta
July 2021

Multi decade analysis of energy transition

Goal:

- Understand drivers of energy transition
  - Policy (market design, climate policy, …), technology, input prices, consumer behavior

Approach:

- Market dynamics driven by private investment decisions (entry-exit)
- Investors are sophisticated (rational, forward looking)
- Profits and performance from detailed model of energy market
- Train econometric model on synthetic data from energy model to obtain global approximation

Storage

Batteries are fundamentally different

 Marginal cost (benefit) is opportunity cost (benefit)

 Opportunity cost depends on price expectations and capabilities

Approach

 Day ahead: directly model battery characteristics and schedule optimally

 Real time: optimally dispatch based on linear program

Price responsive demand

Portion of load is traditional

Portion of load is price responsive

Constant elasticity (a 1% increase in price, decreases quantity by 0.1%)

Demand curve for price responsive demand explicitly modeled

Distributed energy resources: solar + battery

Federal action to improve the resilience of critical infrastructures

- Use standards and grants to foster energy efficiency
- Strengthen the ties between the major interconnections in the United States

Western Interconnection
Includes El Paso and Far West Texas

Eastern Interconnection
Includes portions of East Texas and the Panhandle region

ERCOT Interconnection