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

Electricity

Water

Gas

People
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 -25°F departure)
Coldest temperatures during Texas cold snaps, Fahrenheit

- Dallas
- Austin
- San Antonio
- Houston

- ERCOT extreme winter 18.3° average Feb 2011
- 5.5° average without Feb 2011
Natural gas flow drops sharply on Friday, 12 Feb, *well before* electricity outages on Monday, 15 Feb.
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

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

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

\[
y = 0.0001x^2 - 0.0055x + 0.1405 \\
R^2 = 0.827
\]

\[
y = -0.0025x + 0.1338 \\
R^2 = 0.6635
\]

Source: Black & Veatch report for ERCOT, October 2013
- US natural gas production drops 21%
- TX natural gas production drops 45%
Natural gas prices on February 16

Gas generators are heavily exposed to gas spot market
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 Cold Pushes Texas Power Prices to Record Highs
ERCOT North Hub real-time and day-ahead energy prices

$9,000/MWh energy offer cap

Real-time prices

Day-ahead prices

Source: ERCOT

Source: Brian Bartholomew
Extreme Weather, Extreme Outages Pushed Texas into Blackouts

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

80GW

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

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

Load forecast

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

Load shedding ends on Friday

Load plummets below forecast as blackouts begin

Actual load

Power picks up as plants return from outage

Thermal plant outages

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

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

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

Wind + Solar

Data source: ERCOT

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

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 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)
- Additional 3,000 MW Load-Shed Ordered (Total 5,000 MW)
- Min Frequency 59.302 Hz
Enacted and rejected legislative changes

- **HB16**: Ban retail plans tied to wholesale price → harm price responsive demand
  - Griddy and Octopus Energy, $10/month plus wholesale cost
- **SB2**: ERCOT Board appointed by Governor and Legislature leadership; all must reside in Texas
  - Independent expertise → political appointees
- **SB3**: Weather alert / improved communications
- **SB3**: Texas Energy Reliability Council to write a report on reliability every even year
- **SB3**: Winterization requirements of gas supply chain
  - Determined by Railroad Commission; penalties < $1M
- **SB3**: Practice load shedding events
- **SB3**: Security of supply mapping committee to report by end of year on security of supply
- **SB3**: Emergency pricing program (circuit breaker) after 12 hours at the price cap in 24-hour period
- **Securitization of costs**
  - Natural gas utilities / electric co-ops / broader
- **Dispatchable generation requirement**
- **Assign reserve costs to renewable generators**
- **Berkshire Hathaway Energy plan to build 10GW of gas-fueled strategic reserve**
  - $8.3 billion cost, 9.3% guaranteed return on investment
Reliability

Electricity system's ability to satisfy 100 percent of demand

Measures frequency, duration, and magnitude of shortage events
- system average interruption duration
- system average interruption frequency

Outages are short and localized, caused by routine events that cause demand to spike and supply to drop
- Failure of large units on a windless hot summer day

Resilience

A system's ability to be robust to a wide range of environments

Events are rare and involve systemic failure of many elements
- Cyber attack, extreme cold, etc.

Drop in supply and spike in demand triggered by the same event

Events are system-wide, long in duration, and have implications for other critical infrastructure.
Resilience

Before
- Prepare

During
- Alleviate

Learn
- Observe
- Improve

After
- Recover
Governor and regulator

System operator
Generators
Distribution companies
Retail service providers
Public
Customers

Improve communications
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
Enhance oversight of ERCOT as the electric industry undergoes rapid innovation

- Retain the core elements of the existing governance structure
- Improve oversight to be more responsive to rapid innovation
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?
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")
Key elements

- Periodic clearing
- Sophisticated expression of preferences
- Optimization of gains from trade
- Improved outcome discovery, transparency, trust, and privacy
<table>
<thead>
<tr>
<th>Features of market outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competitive equilibrium quantities and prices exist and are unique when it matters (positive quantity traded and not perfect substitutes)</td>
</tr>
<tr>
<td>Outcome maximizes as-bid social welfare s.t. constraints</td>
</tr>
<tr>
<td>Incentives for truthful bidding are good (and excellent for most liquid products)</td>
</tr>
<tr>
<td>Outcome is as-bid envy free (given prices, everyone gets their favorite bundle)</td>
</tr>
<tr>
<td>Scales to large number of products and participants</td>
</tr>
</tbody>
</table>
Climate policy matters

Global energy related CO2 emissions, 1990-2019

Last updated Tuesday, May 28, 2019
2020 Retiring (Summer Capacity MW) EIA, Mar 2020

United States

Coal
2,939

Natural Gas
1,022

Other
232

Wind
123
# Summer Capacity MW, EIA, Mar 2020

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>477,355</td>
</tr>
<tr>
<td>Coal</td>
<td>225,799</td>
</tr>
<tr>
<td>Wind</td>
<td>105,919</td>
</tr>
<tr>
<td>Nuclear</td>
<td>98,119</td>
</tr>
<tr>
<td>Hydro</td>
<td>79,788</td>
</tr>
<tr>
<td>Solar</td>
<td>39,197</td>
</tr>
<tr>
<td>Other</td>
<td>51,833</td>
</tr>
<tr>
<td>Storage</td>
<td>24,075</td>
</tr>
</tbody>
</table>

### United States

<table>
<thead>
<tr>
<th>Category</th>
<th>MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1,102,084</td>
</tr>
<tr>
<td>Planned Retiring</td>
<td>39,034</td>
</tr>
<tr>
<td>Retiring</td>
<td>4,316</td>
</tr>
<tr>
<td>Change</td>
<td>43,350</td>
</tr>
<tr>
<td>3.9%</td>
<td></td>
</tr>
</tbody>
</table>
Electricity Markets in Transition

A forty-year model of entry and exit

Peter Cramton, Emmanuele Bobbio, David Malec and Pat Sujarittanonta

July 2021

We are grateful to PJM Interconnection for funding and expert help. Funding also from Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany’s Excellence Strategy – EXC 2126/1–390838866 and by the European Research Council (ERC) under the European Union’s Horizon 2020 research and innovation program under grant agreement No 741409.
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