What do the recent blackouts tell us about the current state of decarbonised power systems?

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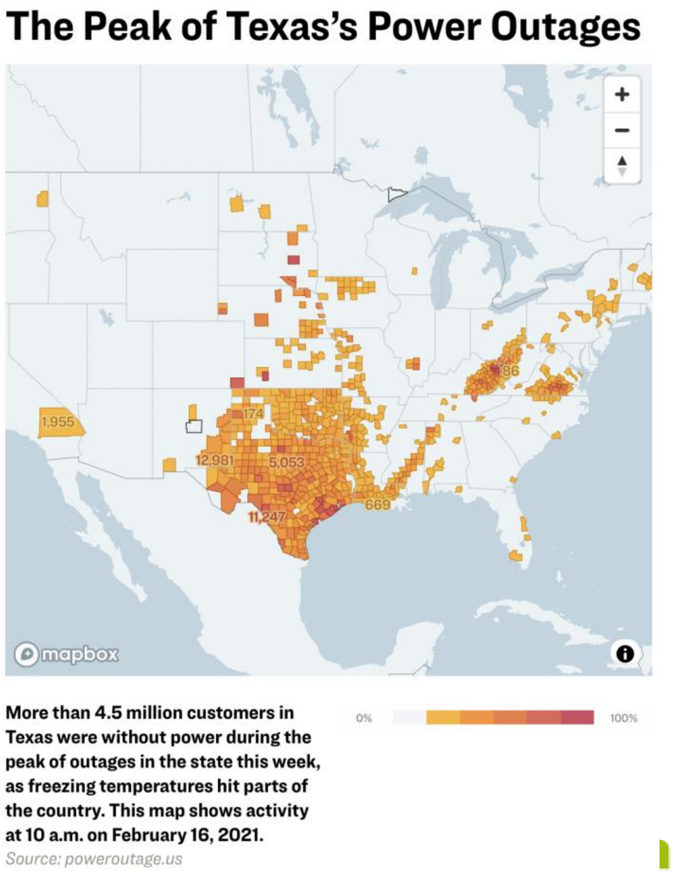
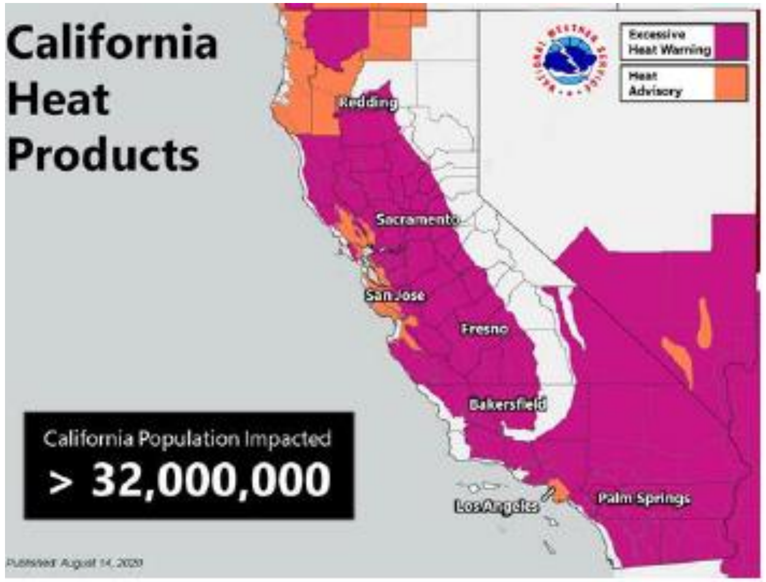
Recent outages

- Australia 2016
- GB: August 2019
- California: August 2020
- Texas: February 2021

- Is there a common theme?





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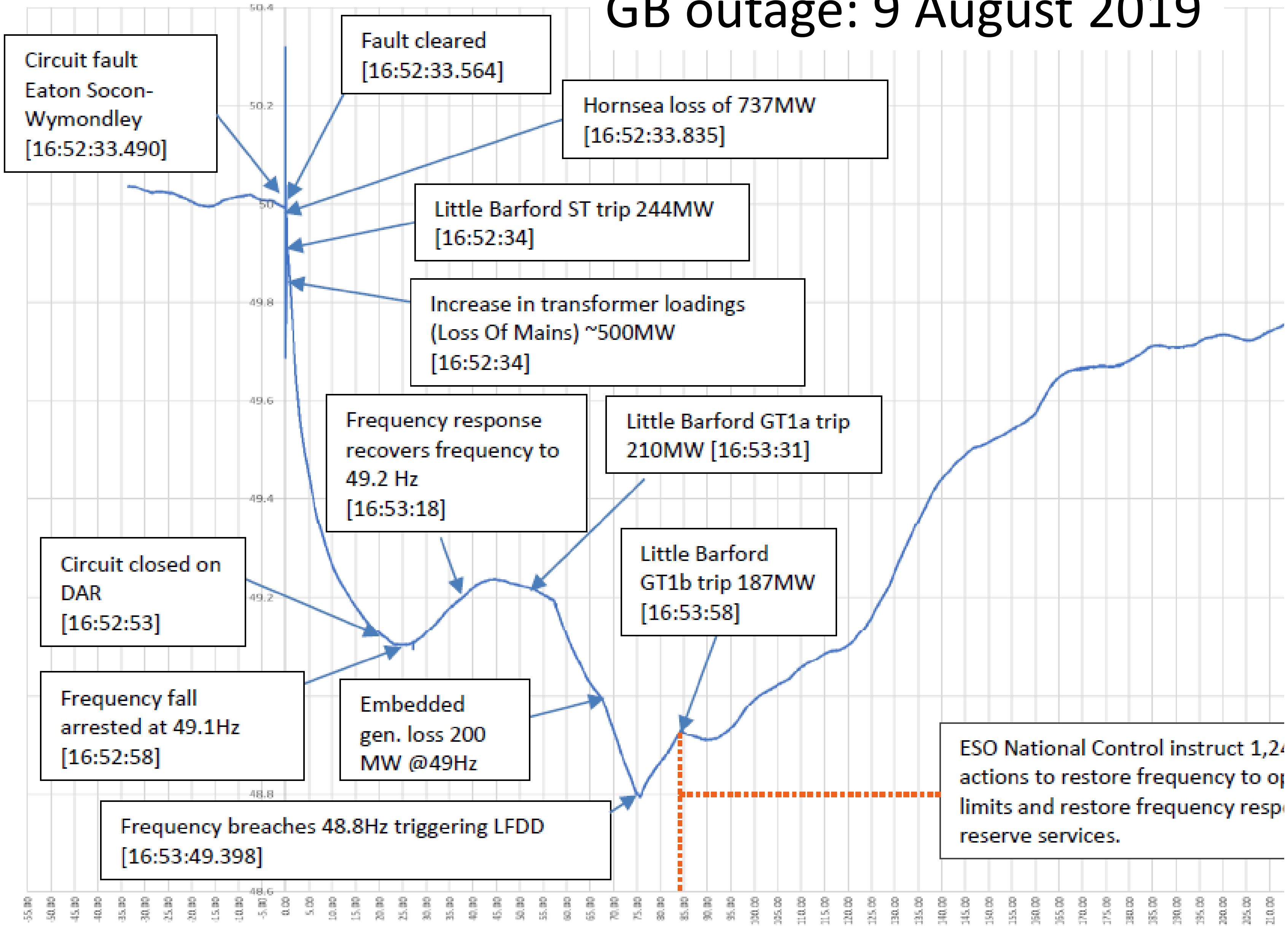
GB outage: 9 August 2019



- Lightening strike – nothing unusual but two power plants tripped: (N-2) event
- Hornsea offshore wind farm (200 miles away) commissioned 7 months earlier
  - Grid Compliance only on interim basis
- Little Barford plant – traditional Combined Cycle Gas Turbine (CCGT)
- Additional loss of DG due to fast frequency and voltage changes inadvertently triggering Loss of Mains protection against islanding
- Under-frequency load shedding (involuntary) when frequency dropped to 48.8 Hz: 1.15M customers, 931 MW
- Full supply restored in 40 mins
- Power system behaved as it was designed to in response to (N-2) event
- Everything OK?

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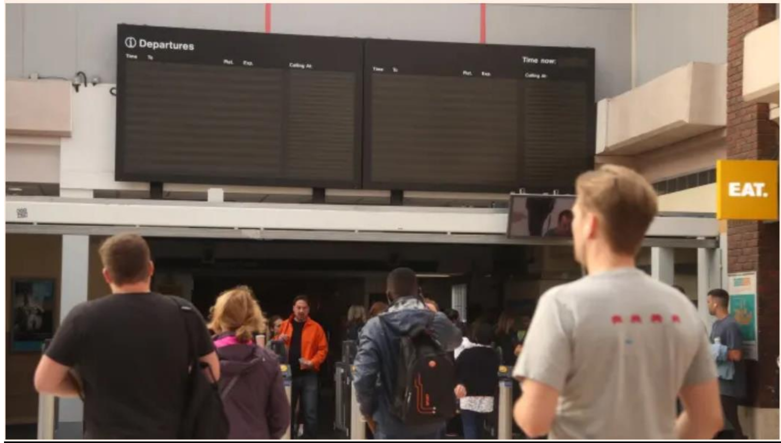
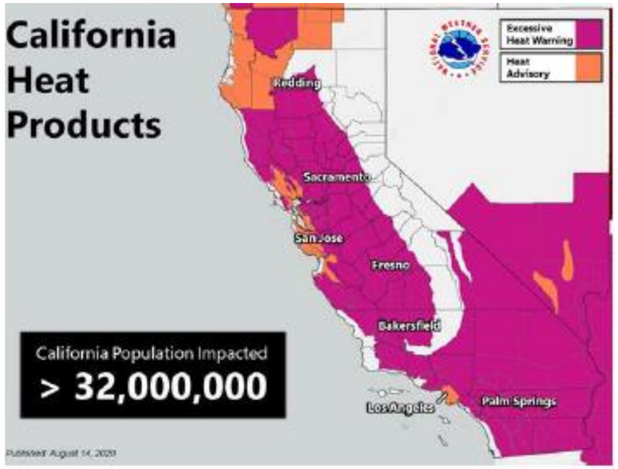
Bialek J. “What does the GB power outage on 9 August 2019 tell us about the current state of decarbonised power systems?” Energy Policy 2020, Vol. 146.

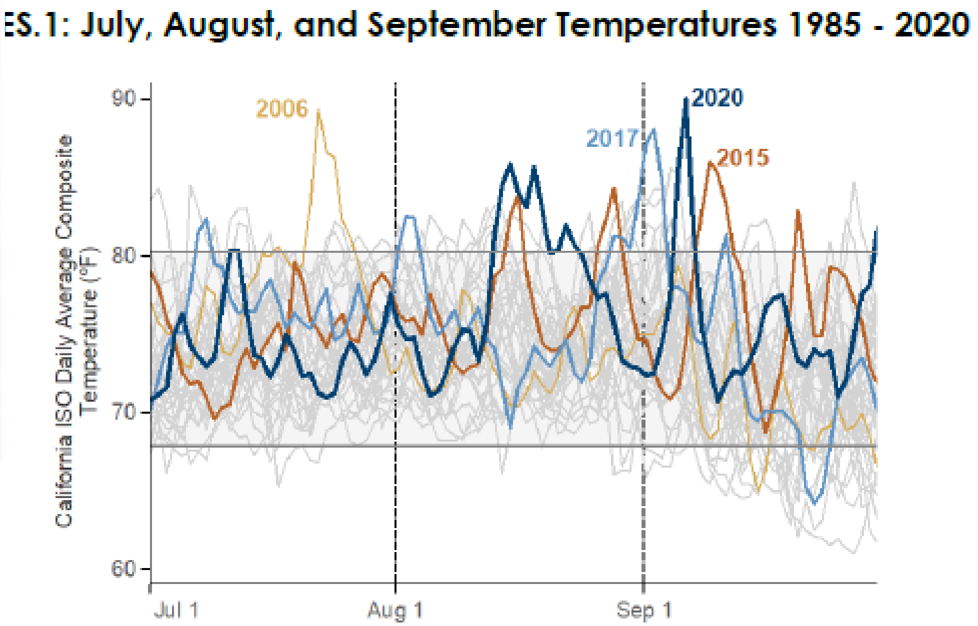
Effects on infrastructure: rail

- It was not the outage itself, which lasted only 40 mins, but a rail disruption which caused public anger
- Perfect storm: Friday evening
- Power supply to the tracks was not interrupted but one class of trains failed when frequency fell below 49 Hz
  - They should have operated down to 48.5 Hz
- Knock-on effect – total chaos:
  - Hundreds of trains cancelled
  - Two main London stations closed for several hours
- Conclusion: need to consider common modes of failure and interconnected infrastructures

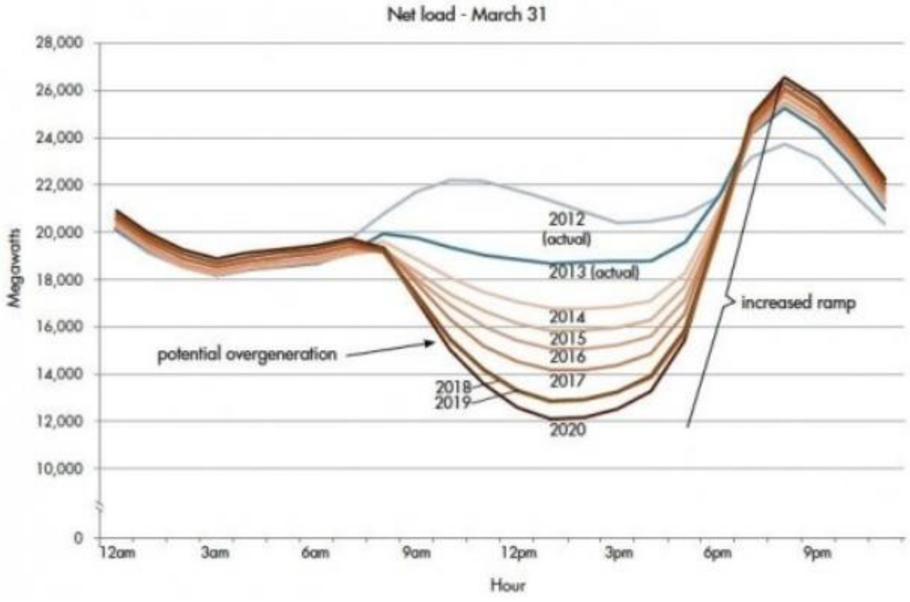


California rotating outages August 2020





- Rotating blackouts over a number of days affecting 32M people
- “The climate change-induced extreme heat wave resulted in demand for electricity exceeding existing electricity resource adequacy (RA) and planning targets”
- “resource planning targets have not kept pace to ensure sufficient resources that can be relied upon to meet demand in the early evening hours.”
    - Duck curve
    - Solar panels provided less power but the demand was still high
- “Some practices in the day-ahead energy market exacerbated the supply challenges under highly stressed conditions”
    - “Any system that can be gamed, will be gamed, and at the worst possible time.” S. D. Freeman, Chair of the California Power Authority, 2001

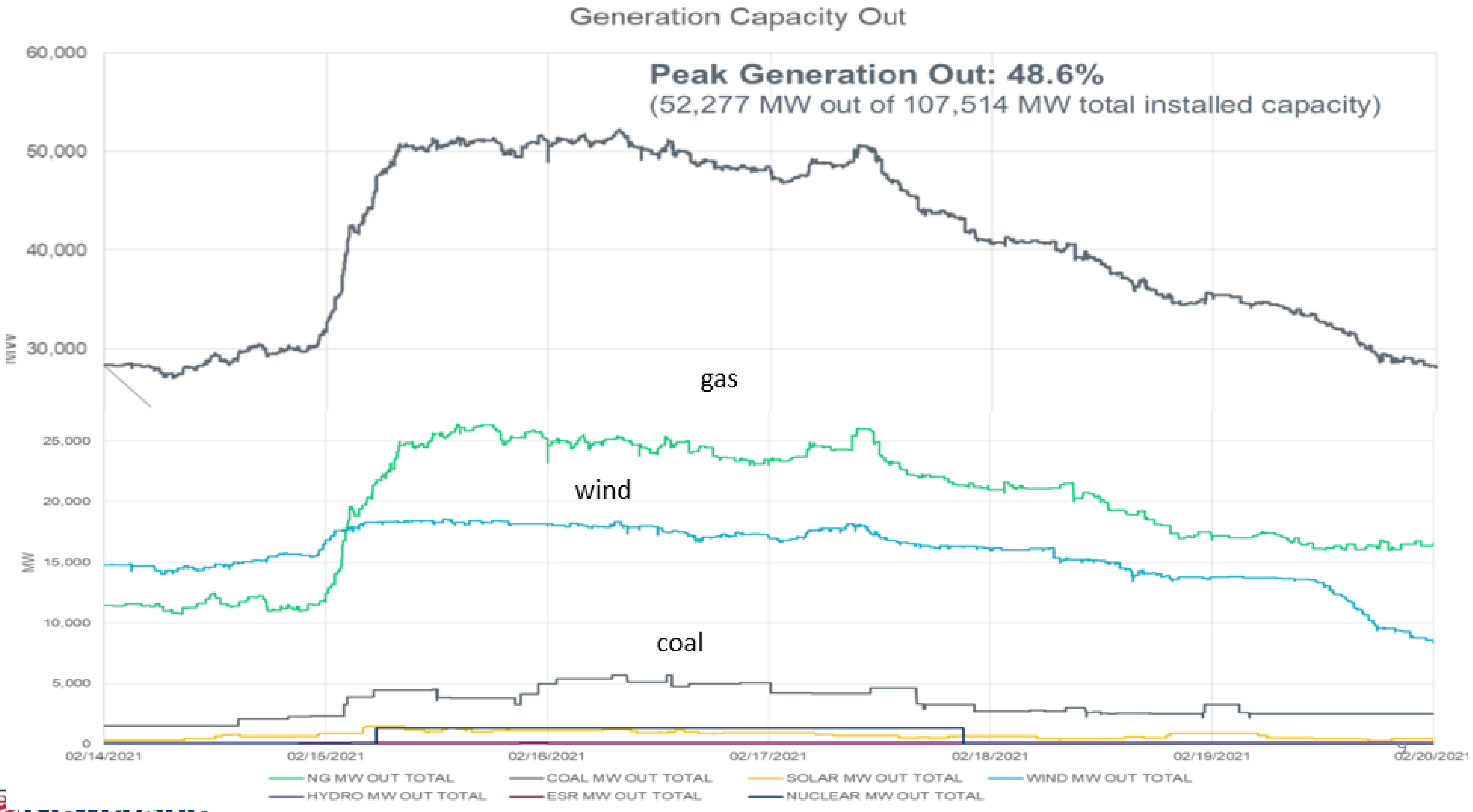


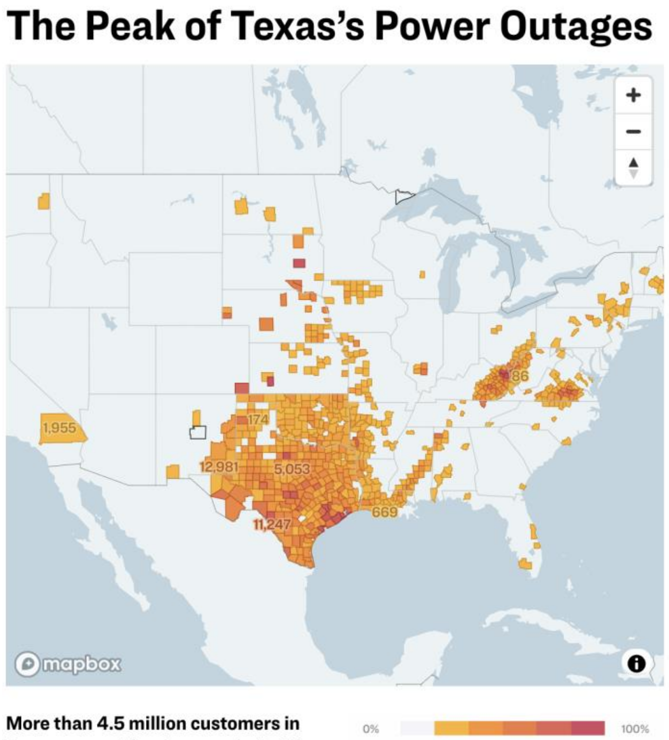
California Independent System Operator

California ISO: “Root-cause analysis. Mid-August 2020 Extreme Heat Wave” January 13, 2021

Texas freeze and blackouts 11-19 February 2021

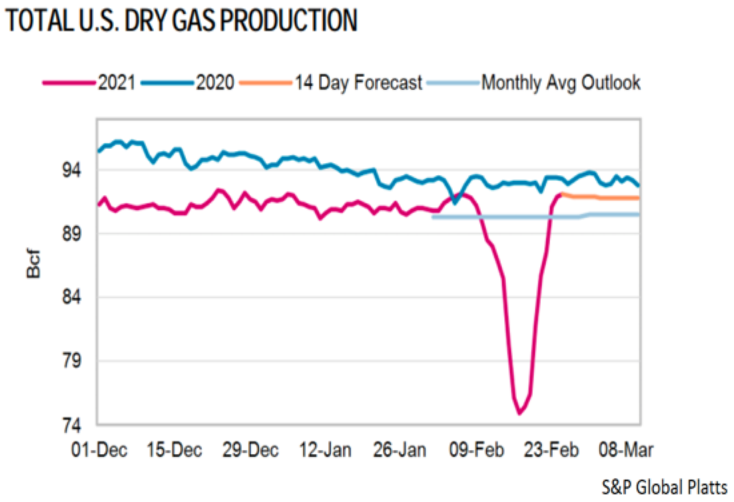
- Texas is a hot weather state – not prepared for ice storms and long-lasting freeze
- 20 GW peak, 800 GWh load shed – 4.5 million customers, most down for nearly a week; little or no rotation of outages
- widespread hunger, cold, discomfort, life interruption, 50+ deaths, pipe and water system freezes, extensive home and building destruction from frozen water pipes





More than 4.5 million customers in Texas were without power during the peak of outages in the state this week, as freezing temperatures hit parts of the country. This map shows activity at 10 a.m. on February 16, 2021.

Source: poweroutage.us



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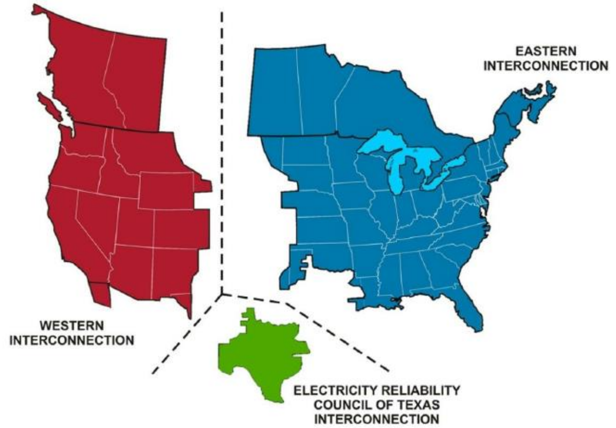
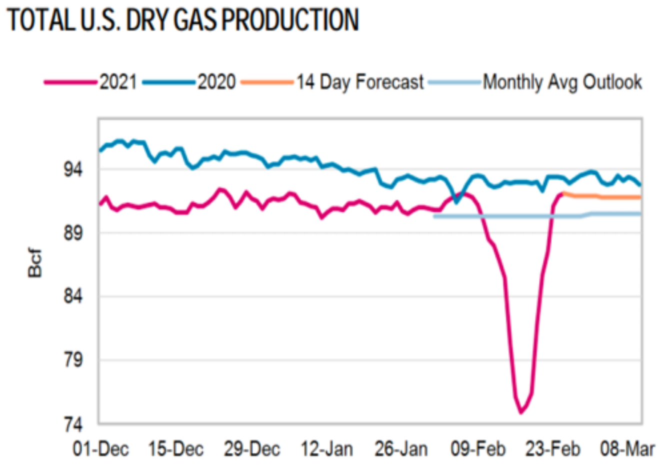
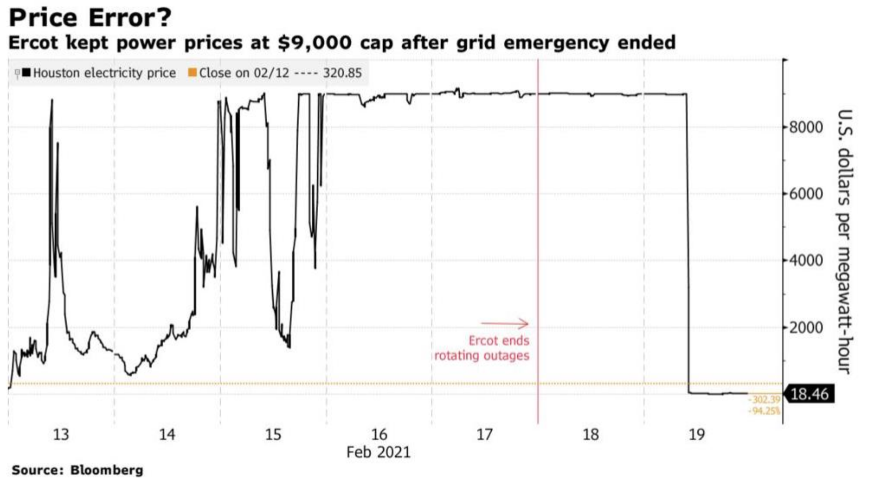
- 4 min 37 secs away from cascading grid collapse and months until full system restoration
- Would a stronger interconnection have helped?
    - Neighbouring regions experienced similar weather and problems
    - The existing (weak) interconnections were underutilized
- ERCOT has an "energy only" market. Would a capacity market have helped?
    - Yes, but no capacity market could protect against 50% generation loss
- Should the energy market have been suspended?
    - Prices were capped at $9000/MWh
    - Gas prices rose too - interactions between the electricity and gas markets
    - Windfall profits for generators, huge losses for consumers
        - Are the price signals meaningful for such an extreme and rare event?
- Markets blamed for preferring short-term profits over long-term security of supply
    - A similar event Feb 2011, US southwest incl. Texas: 4.4M customers affected but shorter (8h vs 71h) less severe (4 GW vs 20 GW load shed) and not affecting gas supplies
    - 2021 Texas freeze was a more severe "black swan" event
    - No compulsory weatherization, deferred to plant owners







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Old world - 20th Century





- Controllable synchronous generation, passive demand
- SO had detailed models of all the system elements (grid, generators, demand): omnipresent and omnipotent god
- Slow changes in technology giving time for getting operational experience
- The past gave a good guidance about the future
- The system was **robust**:
    - SO knew how to deal with “known unknowns”
    - (N-1) reliability criterion served well

The brave new wold (last 10-15 years)

- Fast changes in technology : wind (offshore!), solar, DG, active demand, batteries, smart grids, EVs etc.
- Often little operational experience, rush to commission – see Hornsea
- “Unknown unknowns”: new controls with unknown interactions and modes of failure (Hornsea)
- Common modes affecting interconnected infrastructures (GB, Texas)
- Climate change-induced changes in weather patterns (Australia, California, Texas)
- Past experience does not provide a good guidance any more
- The old world of omnipresent and omnipotent System Operator is gone
- System Operators were caught off-guard by rapid changes in technology (GB) and weather patterns (Australia, Texas and California)
- The system is not **resilient** : SOs were not able to respond to disruptive events, unknown and common modes failures
- Those changes will accelerate due to:
    - zero-emission targets (changes in technology)
    - climate change-induced changes in weather patterns

What to do?

- Raise the security standard to (N-2) to deal with unknown modes of failure (GB)?
  - Very expensive
  - But security standards should be reviewed (California, GB)
- Design the system to withstand high-impact low-probability (HILP) “black swan” events?
  - uneconomical
- Use more widely statistical tools?
  - Of course, but statistics are based on the past and the future will be different
- What to do?
  - combine **robustness** with **resilience**
  - **Robustness** (20th Century): being not surprised by events (react to known unknowns)
  - **Resilience** (21st Century): being prepared to be surprised (react to unknown unknowns)
    - Emphasis on restoration
    - Rely more on novel controls rather than costly passive redundancy to maintain security (e.g. (N-1))
    - Microgrids

Modifications to GB Security and Quality of Supply Standard (GB SQSS)

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G. Andersson: “Power system security: why and how” IEEE Power & Energy, March/April 2021

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