Overview of Renewables in the ERCOT System

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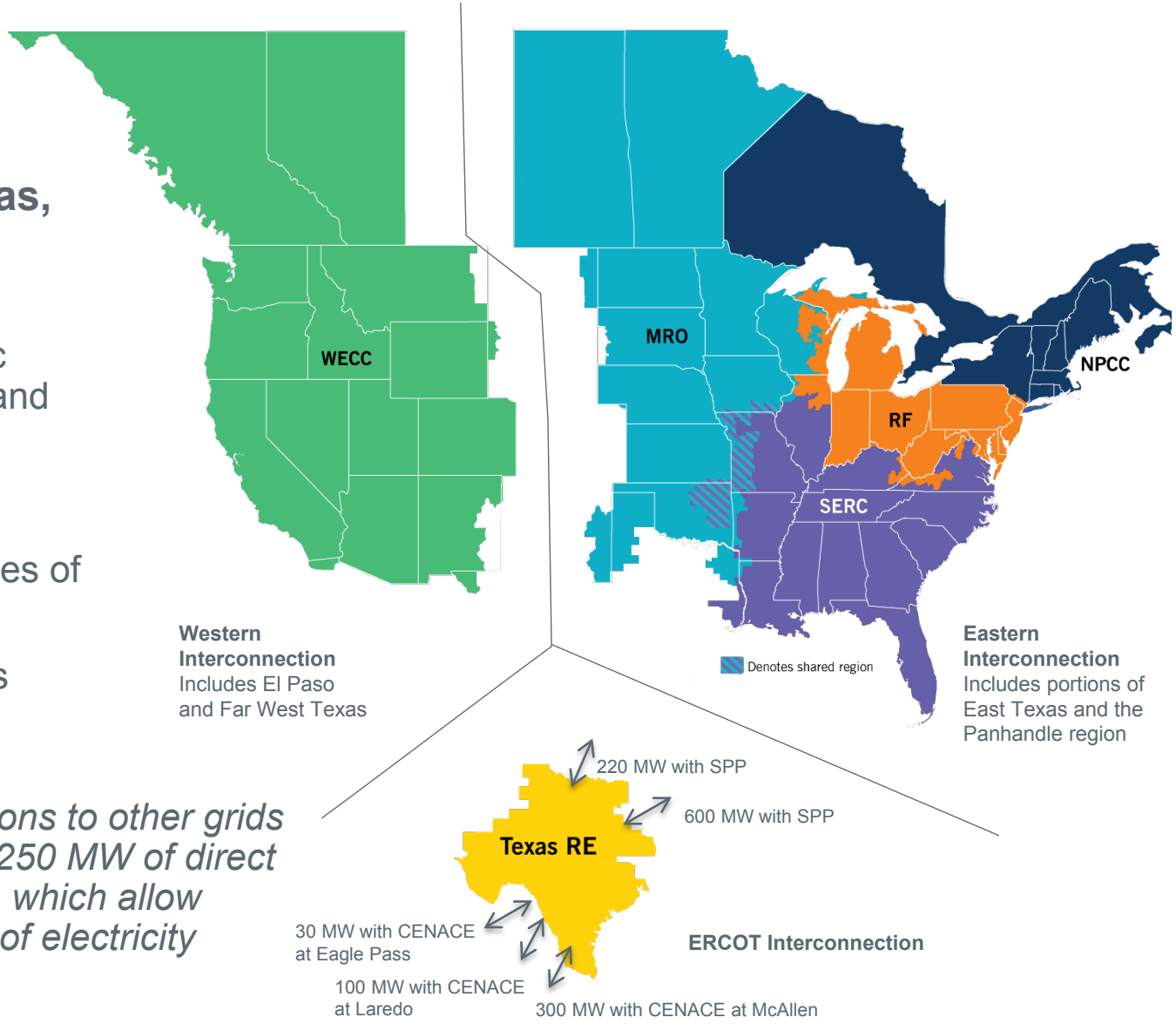
Outline

- ERCOT Overview
- Current Status of Wind, Solar and Storage
- Variable Renewable Energy Resources Integration Timeline
- Key Success Factors

The ERCOT Region

The interconnected electrical system serving most of Texas, with limited external connections

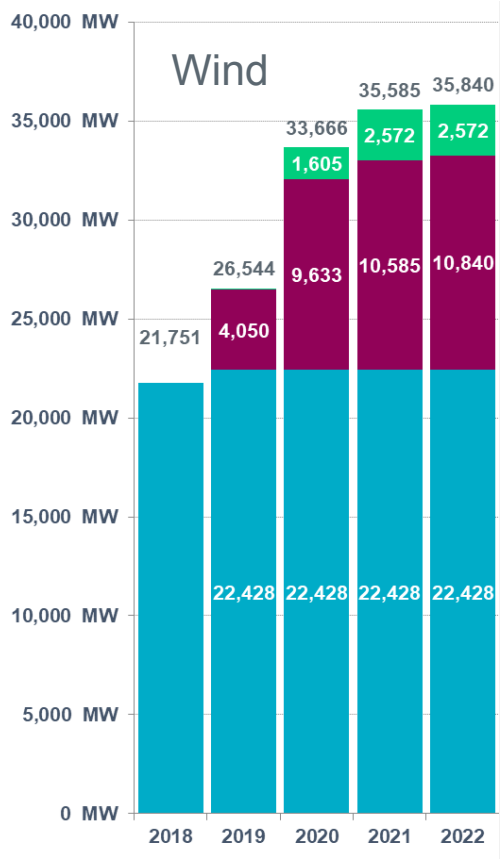
- 90% of Texas electric load; 75% of Texas land
- 74,666 MW* peak, August 12, 2019
- More than 46,500 miles of transmission lines
- 650+ generation units (excluding PUNs)



ERCOT connections to other grids are limited to ~1,250 MW of direct current (DC) ties, which allow control over flow of electricity

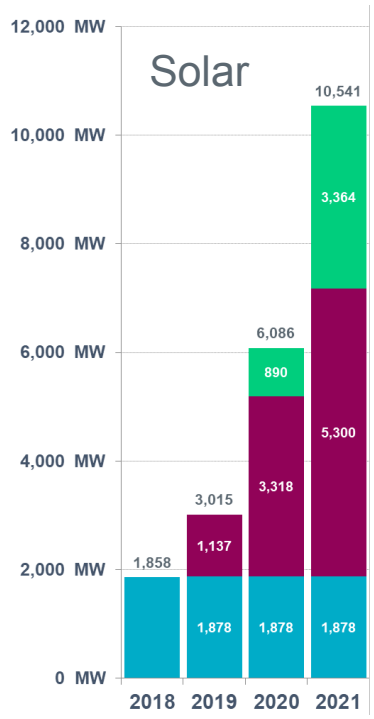
*preliminary operating data

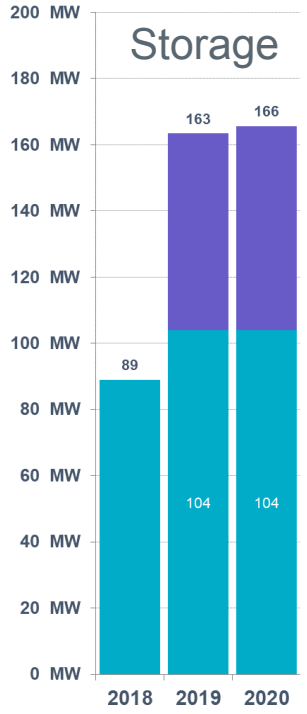
Inverter-Based Resources in ERCOT, as of September 2019



Wind Generation Records (instantaneous)

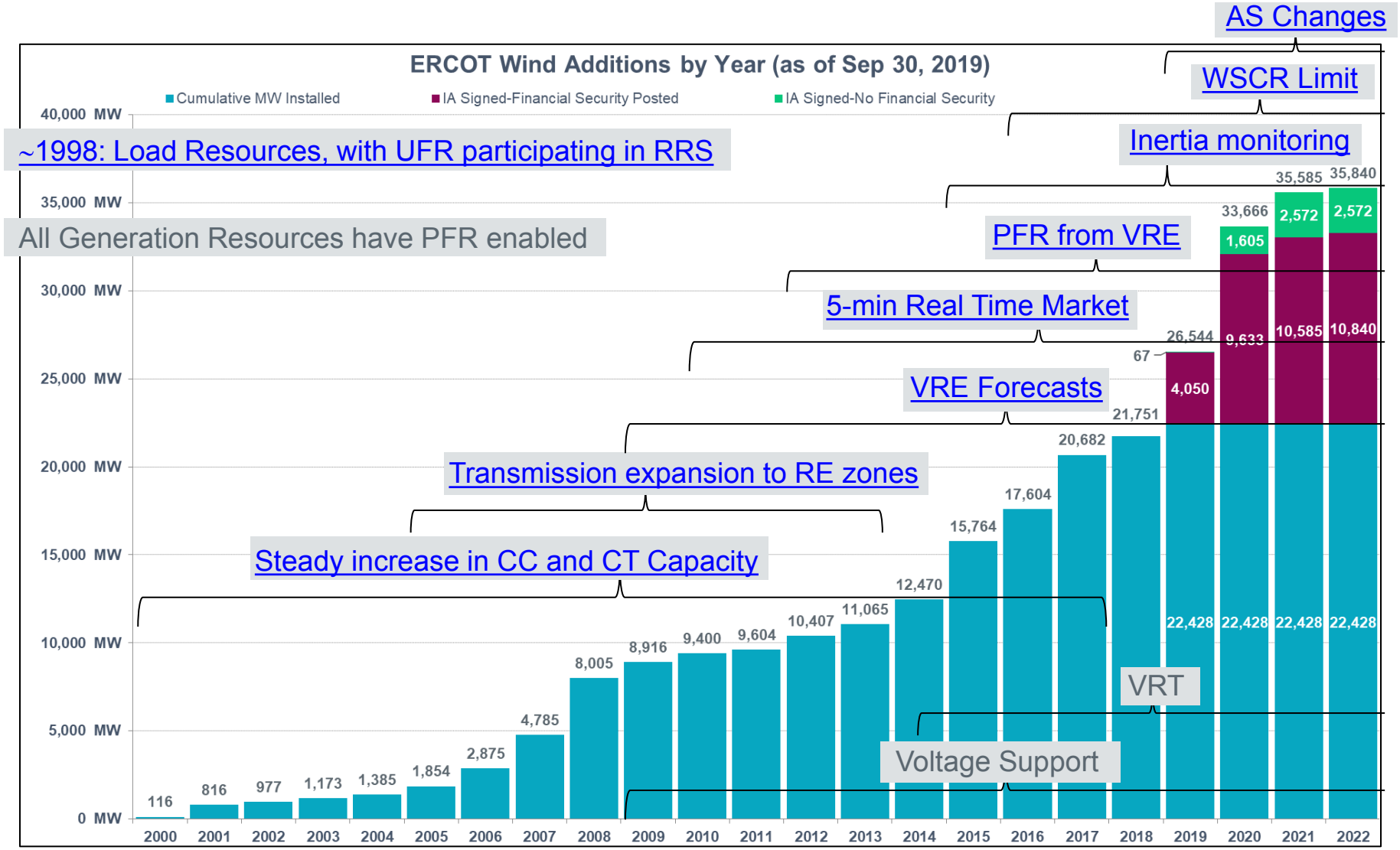
- Output: 19,672 MW
  - Jan. 21, 2019, 7:19 p.m.
- Penetration (load served): 56.16%
  - January 19, 2019, 3:10 a.m.
  - Total MW Served by Wind = 17,406 MW



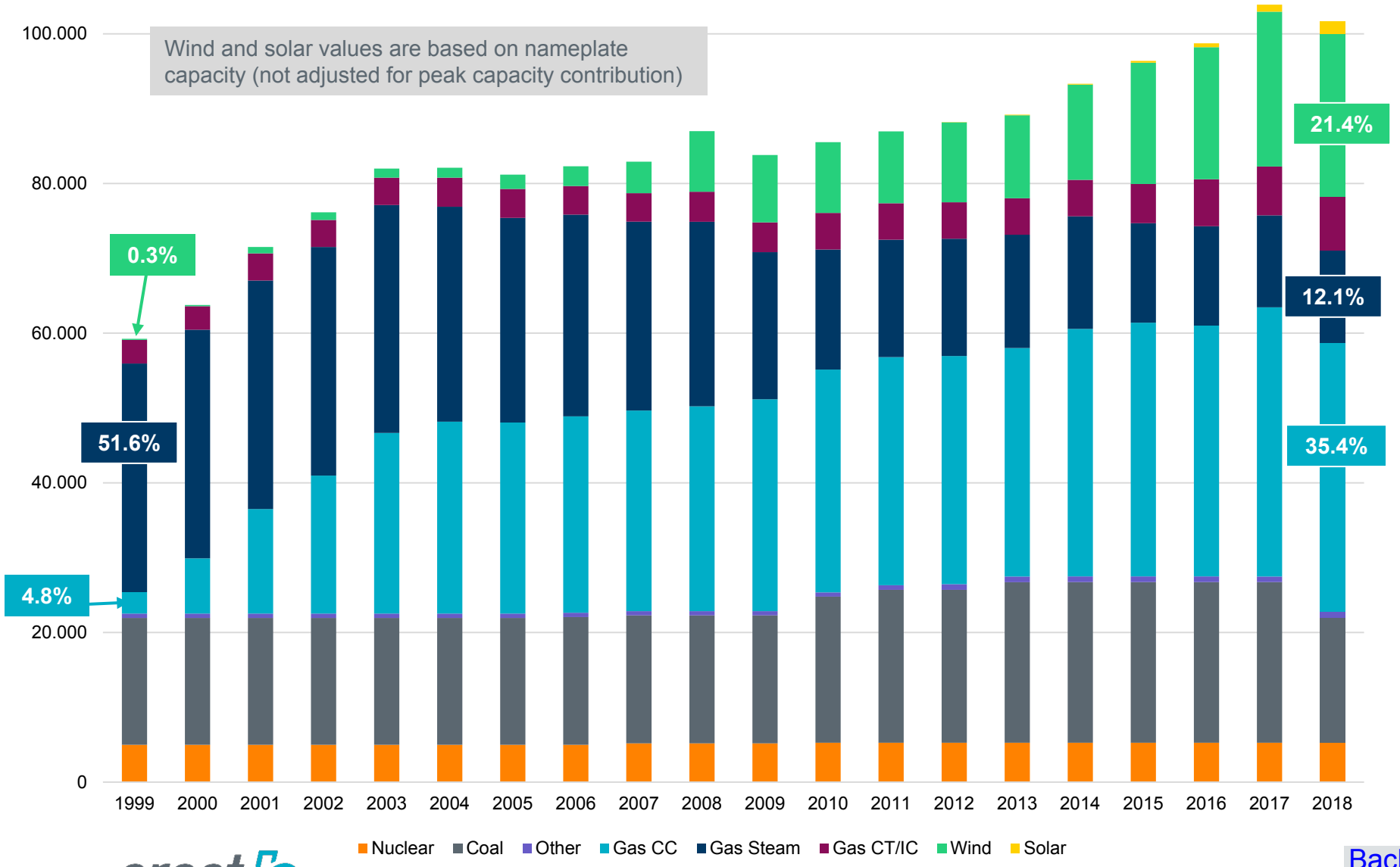


Cumulative MW Installed | IA Signed-Financial Security Posted | IA Signed-No Financial Security | Other Planned

VRE Integration Timeline



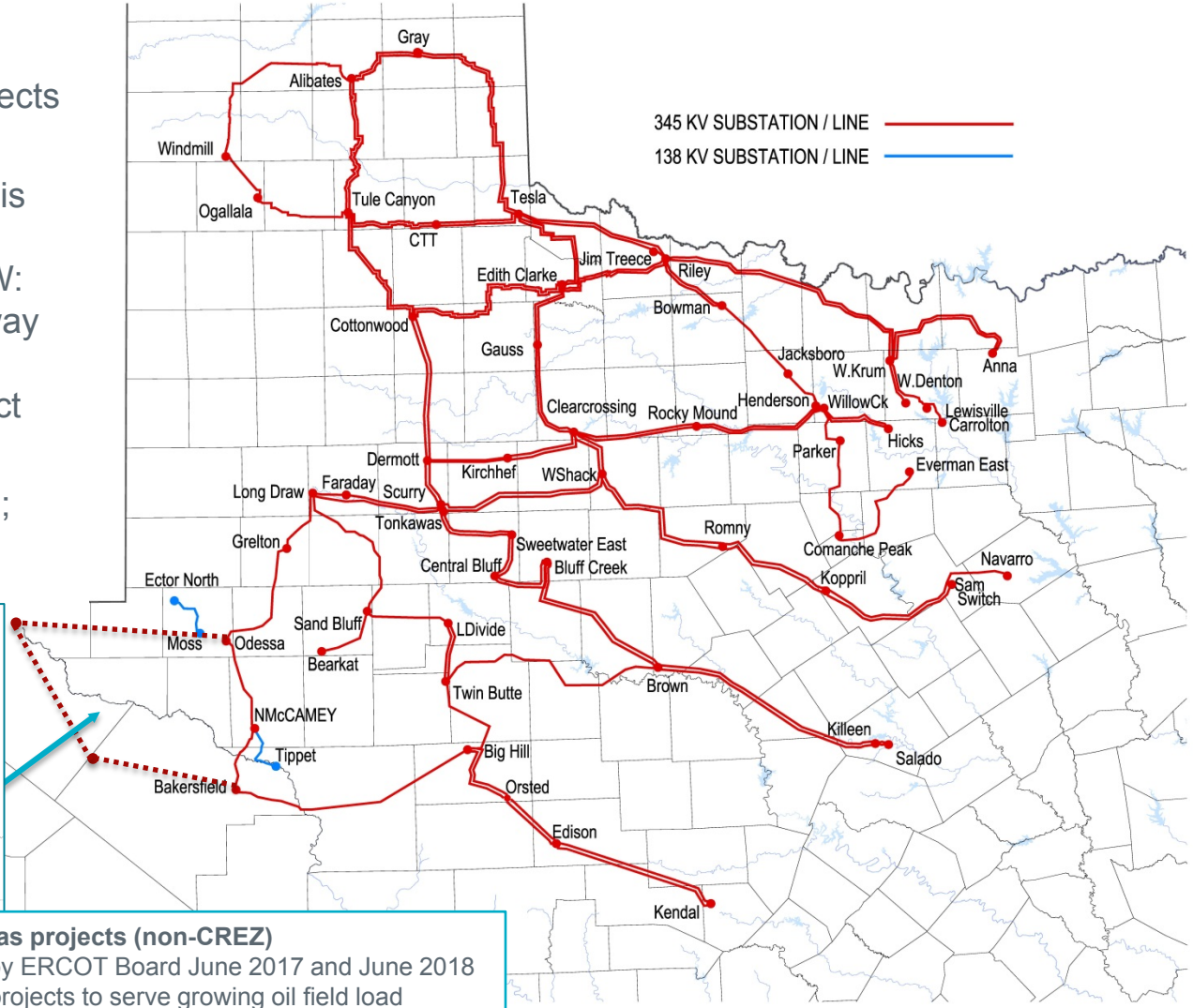
ERCOT Installed Capacity; Increasing Fleet Flexibility

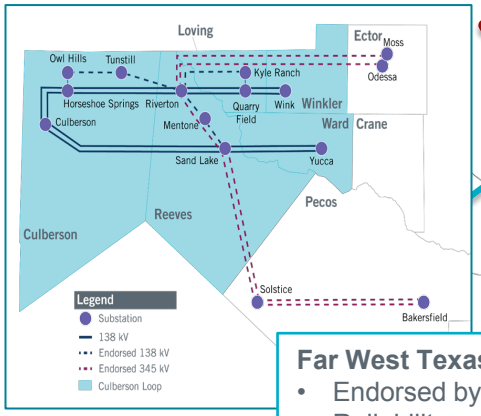


Back

CREZ Transmission and West Texas Solar (2010-2013)

- As of Jan. 30, 2014, the CREZ transmission projects were complete.
- The transmission plan is designed to serve approximately 18.5 GW:
  - ~3,600 right-of-way miles of 345-kV
  - $6.9 billion project cost
- Lines are open-access; use not limited to wind





Far West Texas projects (non-CREZ)
- Endorsed by ERCOT Board June 2017 and June 2018
- Reliability projects to serve growing oil field load
- Expected in-service date of 2020

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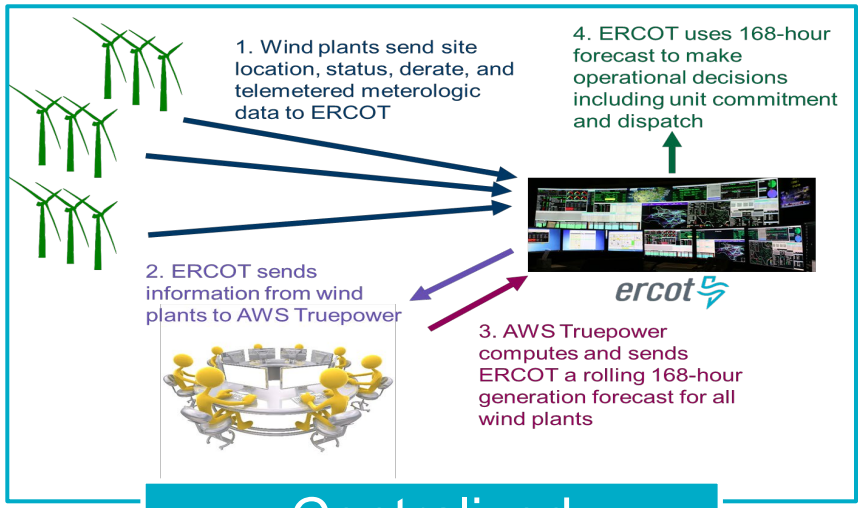
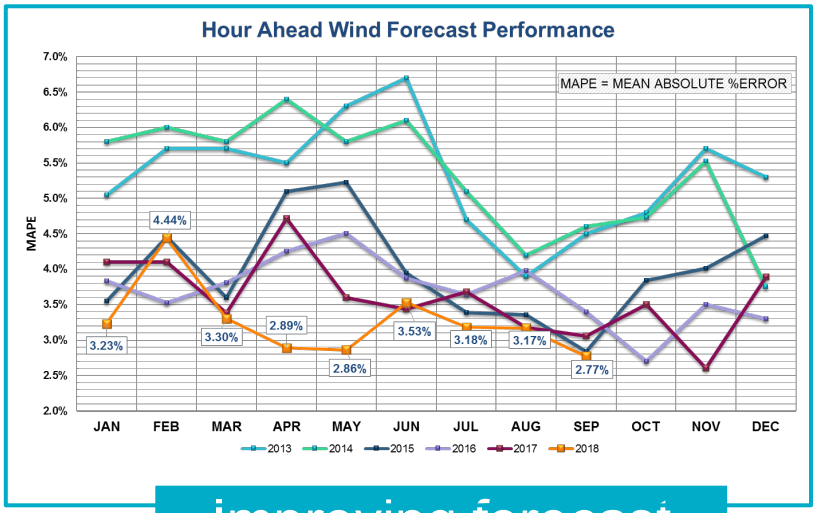
Wind Forecasting, 2009 - Present



Centralized forecasting



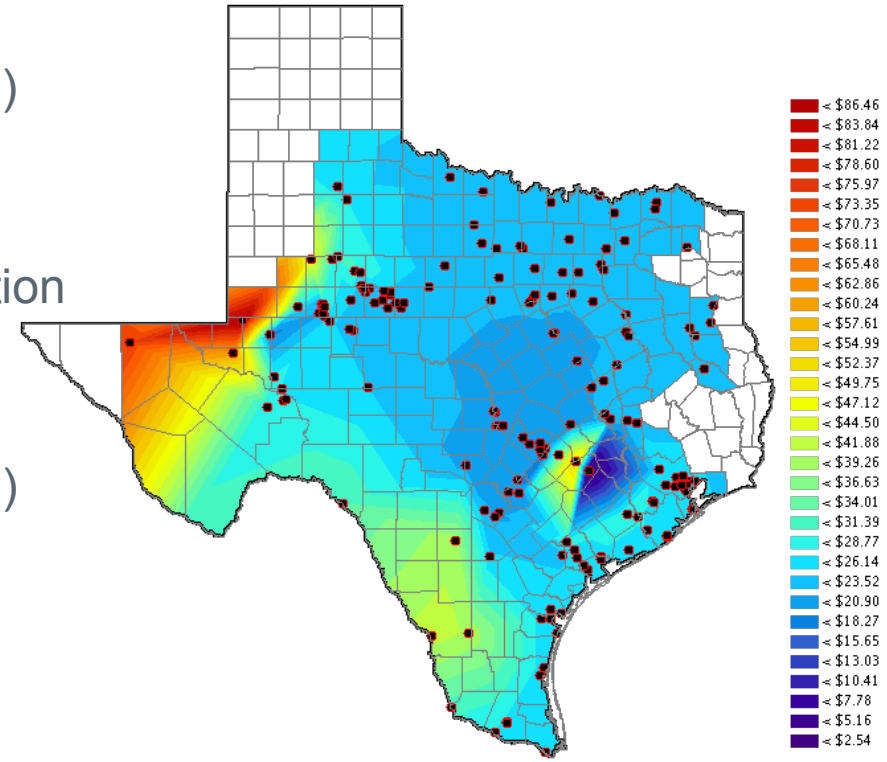
improving forecast accuracy

- Wind forecasting in use since 2009, initially 48-hour outlook
- Solar forecasting was introduced in 2015
- Currently, ERCOT uses a 168-hour rolling forecast with hourly resolution for all wind/solar resources.
- Average hour ahead wind forecast error is 3.35% in 2018

Back

Nodal energy Market, 5-min Real Time Dispatch, 2010

- Generator self-commitment; ERCOT makes residual reliability commitments
- Voluntary Day-Ahead Market (DAM); Ancillary Services are procured in DAM, co-optimized with energy
- All generators (including renewables) submit offers for generation output
- Real-Time market clears every five minutes, using the cheapest generation to serve the load, subject to transmission constraints.
- All generators (including renewables) receive output level instructions and locational marginal prices



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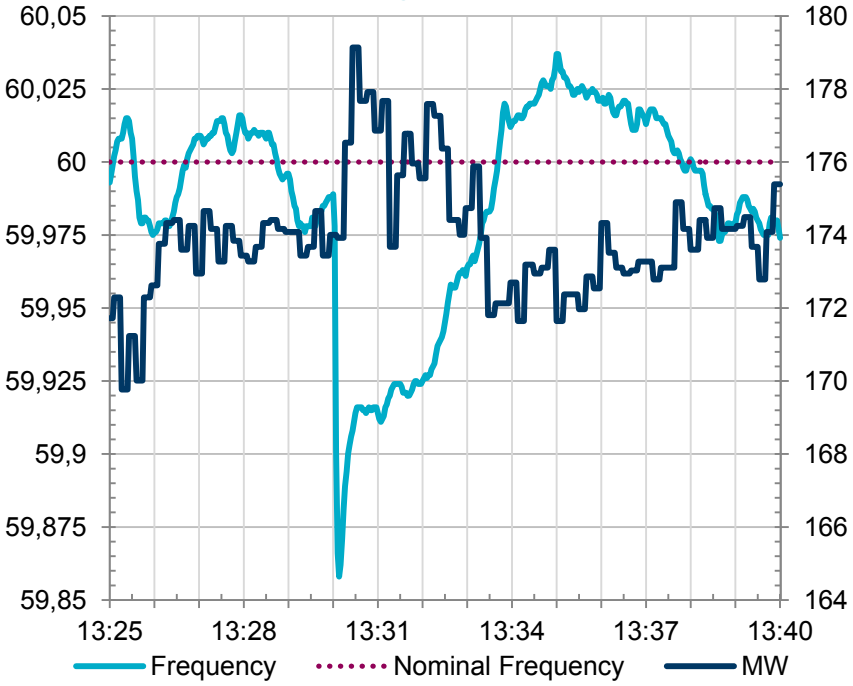
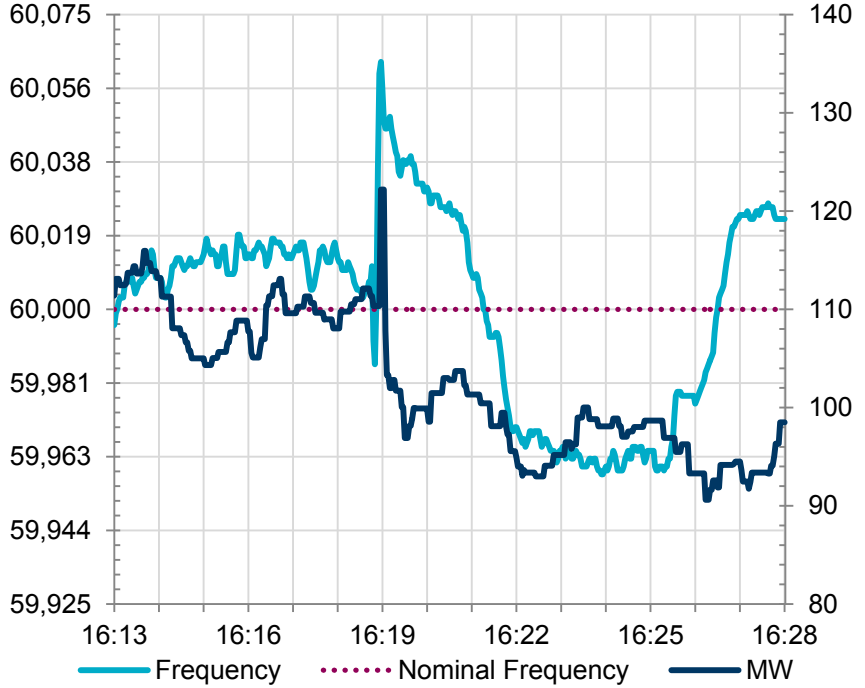
Primary Frequency Response from Wind and Solar, 2012

- Requirement for all wind and solar resources with interconnection agreements after 2008 to provide a “governor-like” response;
- To date, about 2000 MW of older plants are exempt;
- In 2016 the deadband for **all** generation changed to from 36 to 17 mHz

Wind Resource Response to Low Frequency 07/13/2016



Wind Resource Response to High Frequency 08/25/2015



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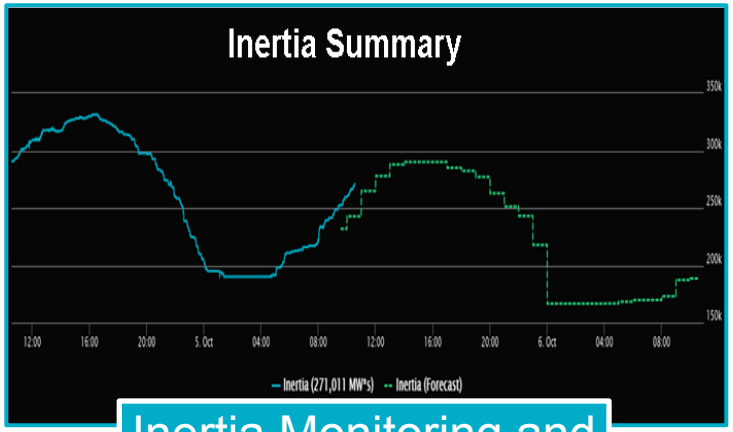
Reliability Risk Desk, Situational Awareness

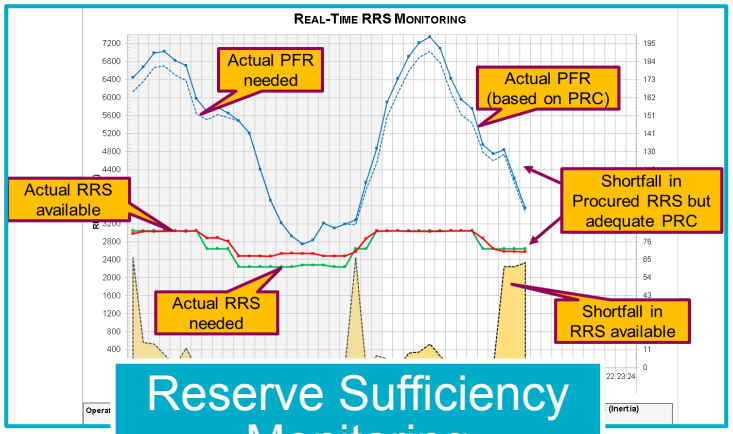


Inertia Monitoring and Forecasting

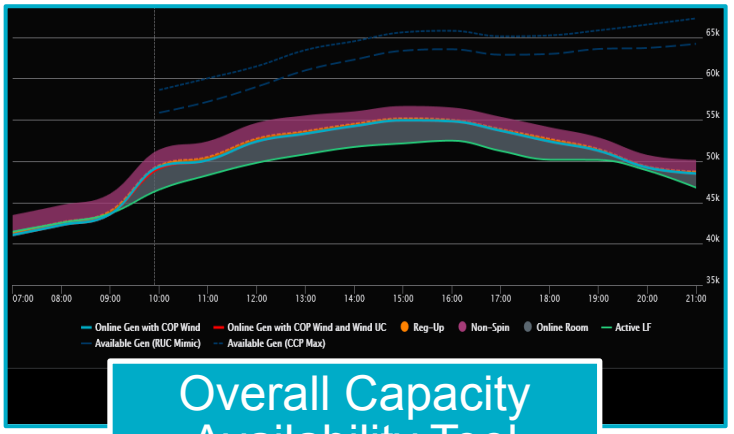
- 120 GW*s >= Inertia Normal
- 120 GW*s > Inertia >= 110 GW*s Yellow
- 110 GW*s > Inertia >= 100 GW*s Orange
- 100 GW*s < Inertia Red

Emergency BPs	Inactive
System Inertia	99,999 MW-s
SCED	00:04:00
RLC	00:00:06
STLF Forecast High	21.6
STLF Next 30 Mins	Normal
QSE ICCP	Normal

Critical Inertia alerts



Reserve Sufficiency Monitoring



Overall Capacity Availability Tool

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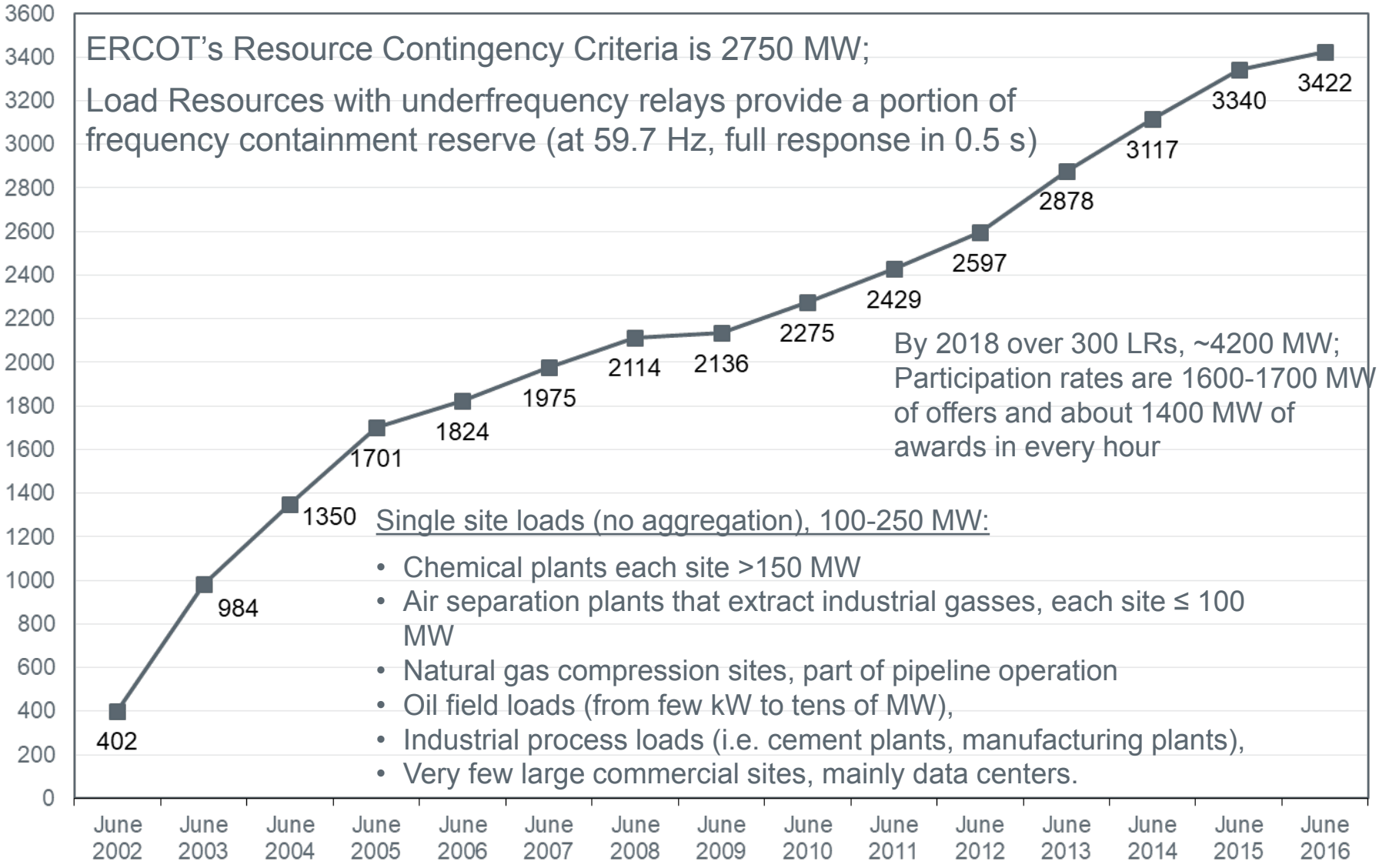
Load Resources Providing RRS since 1998



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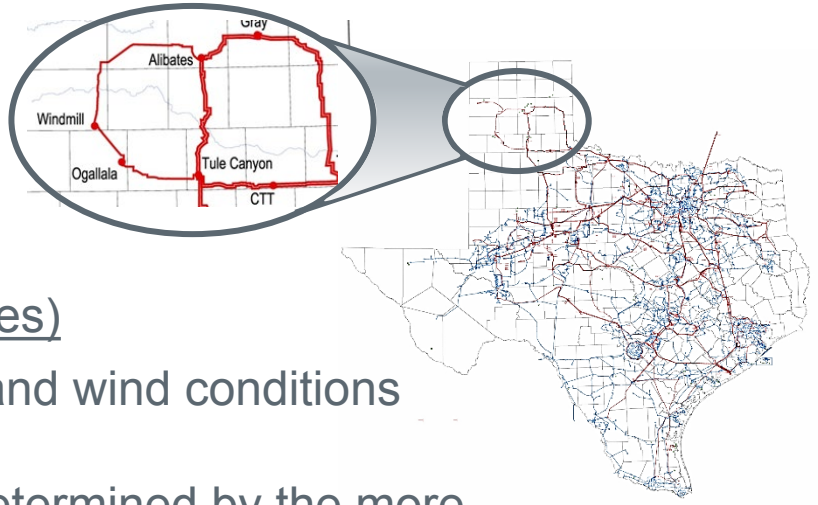
Weak Grid Issues and WSCR/Voltage Satiability limit calculation in near Real-Time, 2016

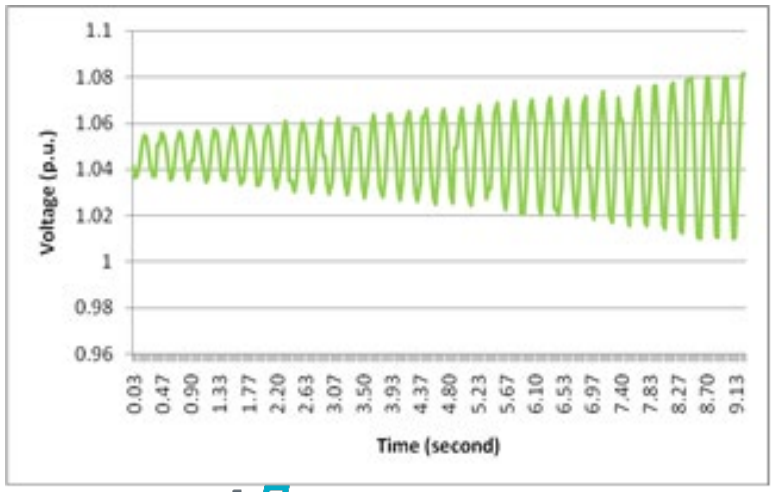


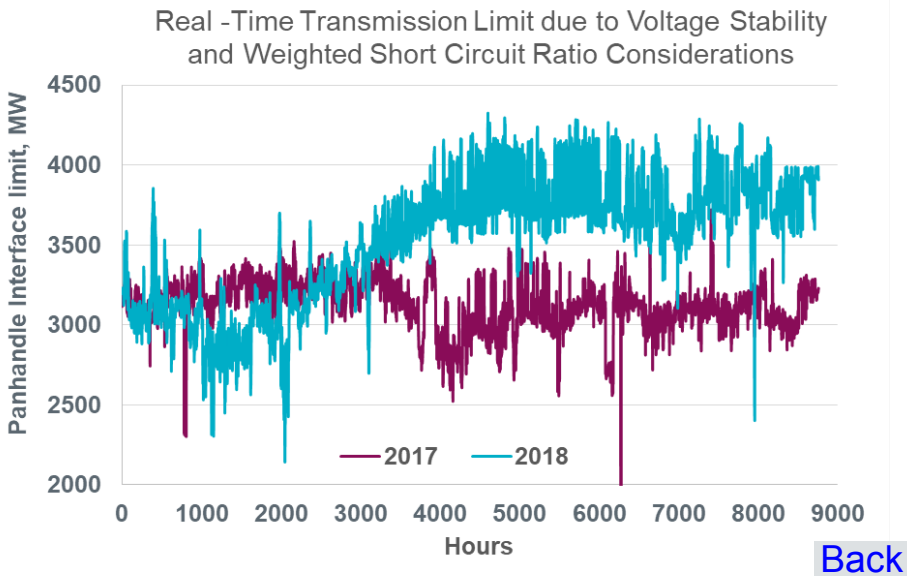
Weak Grid Challenge:

- ~ 4 GW in service, ~1.6 GW planned
- No local load or synchronous generators
- System Strength/Voltage support issues

Real Time Limit Assessment (every 10-minutes)

- WSCR assessment based on actual grid and wind conditions
- Voltage Stability assessment
- Panhandle Transmission Interface Limit determined by the more conservative of the two assessments





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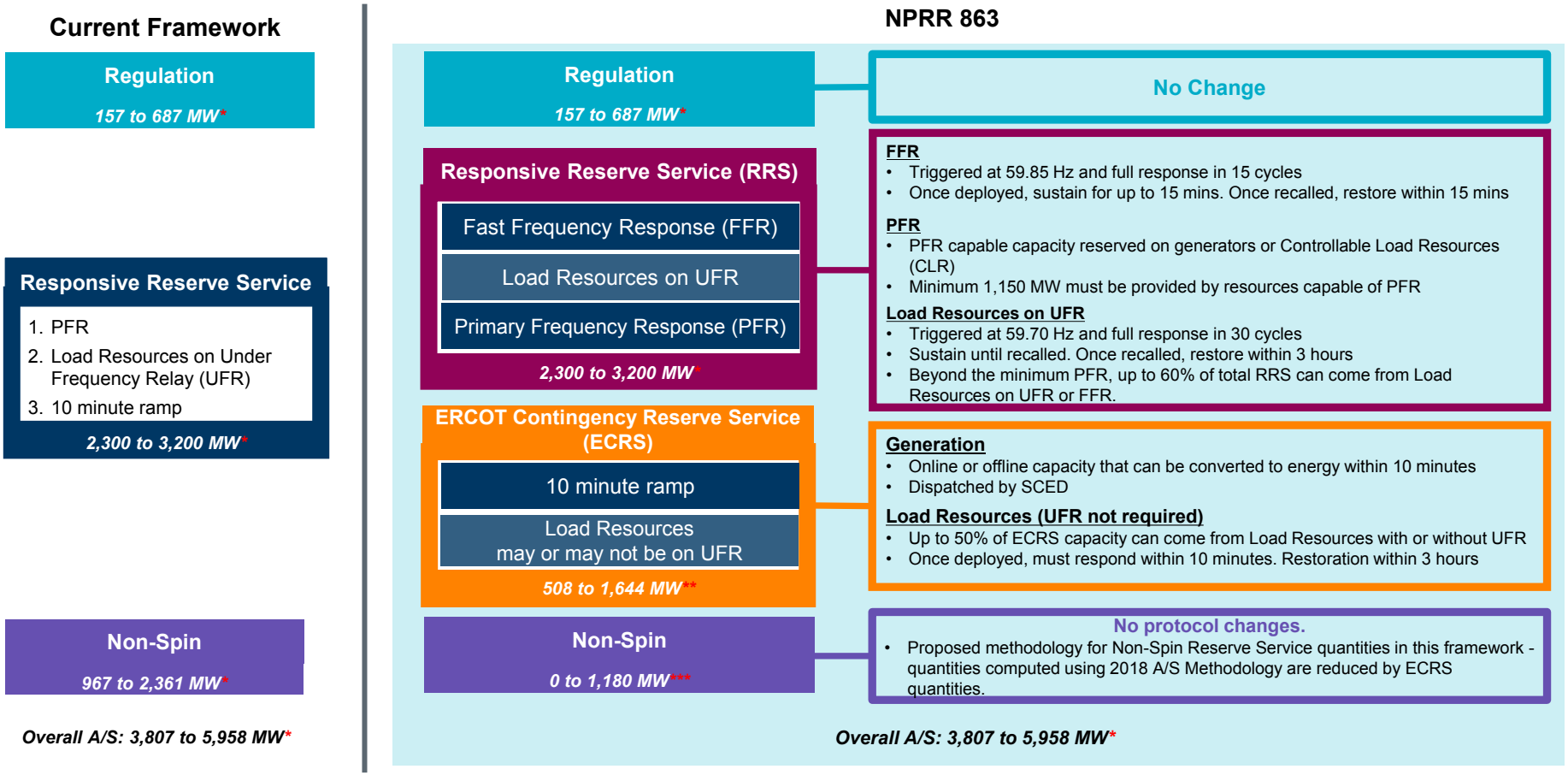
Revision to the AS Product Set Approved

Current target for FFR implementation is March 1, 2020

ECRS will be implemented no earlier than January 2022



*Quantities computed/estimated using 2018 Ancillary Service Methodology. **Quantities estimated using this reference. ***Quantities estimated using this reference and method in box on far left.
For Discussion Purposes Only. The intent of this slide is to represent NPRR 863 (with STEC comments from 10/1/2018). Protocol language prevails to the extent of any inconsistency with this one page summary.

Key Success Factors

- Granular real-time dispatch and accurate forecasting is key;
- Primary Frequency Response Capability enabled on all online resources provides valuable safety net for the system;
- Real-time awareness tools in the control room are essential for efficient and reliable operations with high levels of renewable resources;
- Real-time limit calculation based on actual system and resource conditions;
- Ancillary Services can satisfy essential reliability needs for the system
  - Use market-based solutions as much as possible
  - Design products to attract load participation along side generation
- Some of the reliability requirements need to be implemented through grid codes. Modern renewable generation technology can provide grid support.

Resolving integration issues increasingly requires ongoing coordination between grid/market operators, generation owner/operators and turbine/control manufacturers

Thank you! Questions?

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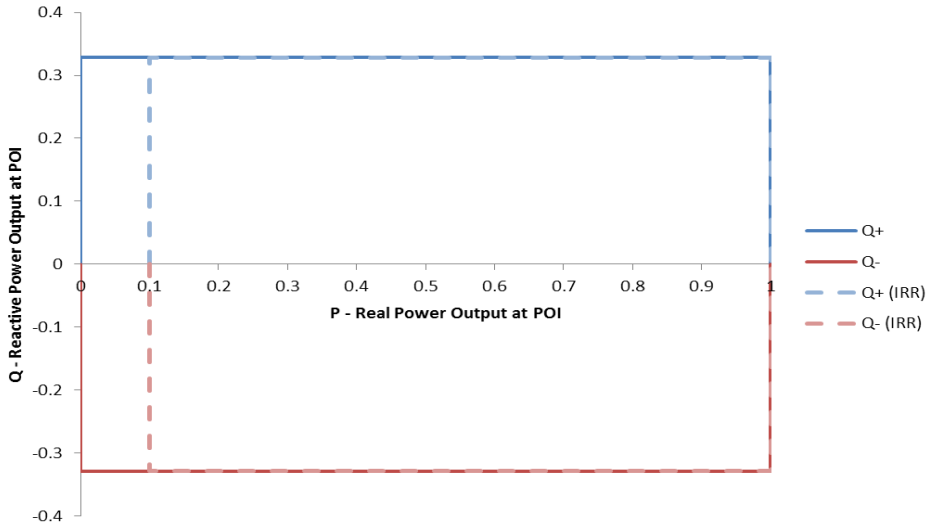
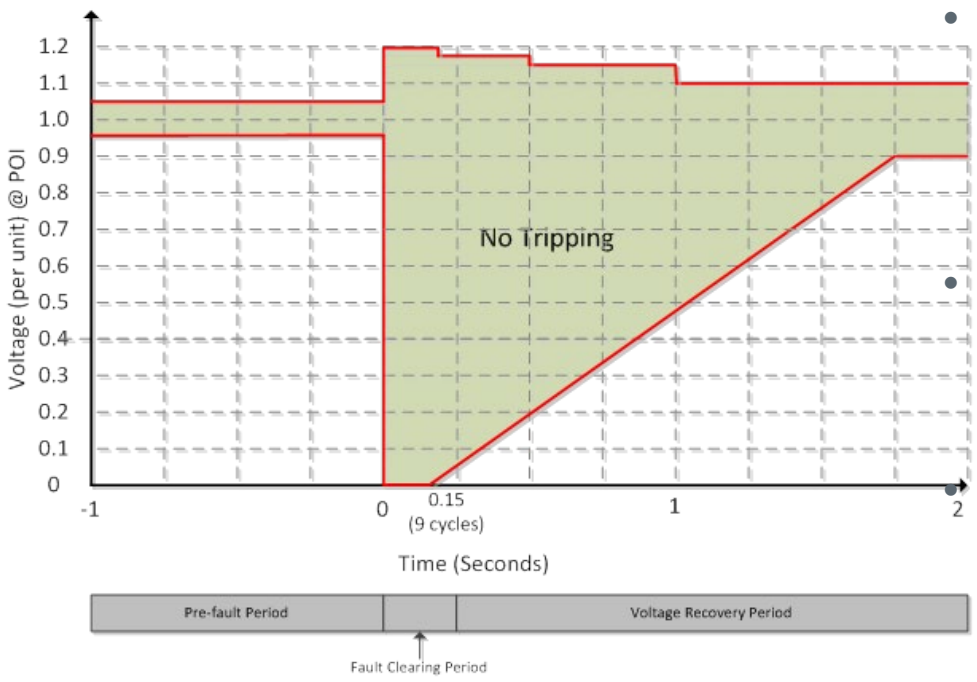
APPENDIX

Voltage Support Requirement, 2008

- Generation Resources greater than 20 MVA shall operate with AVR in voltage control mode to maintain voltage set point at the point of interconnection;
- Reactive power capability of 0.95 lead/lag (at P_{max}) is required at all MW output levels ≥10% of the Renewable Resource nameplate capacity;
- The requirement may be met through a combination of the Resource's VAr capability and/or dynamic VAr capable devices.



Low and High Voltage Ride Through, 2014



No Tripping, No Ceasing to Inject:

- Remain interconnected to the grid
- Provide support to recover the voltage

HVRT:

- Maintain active power
- Absorb reactive power

LVRT:

- May temporary reduce active power to increase reactive power support
- Recover active power shortly after fault is cleared