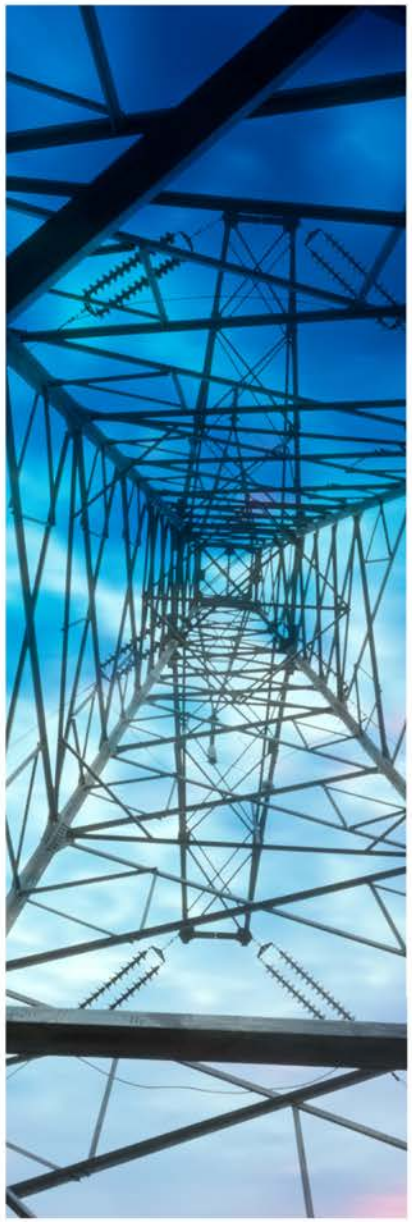

Report on Existing and Potential Electric System Constraints and Needs

December 2019

Key Takeaways

- Transmission improvements planned for **Far West Texas** are sufficient to meet the current load forecast of oil and gas development. However, if load grows faster than anticipated, new projects will likely be needed. ERCOT recently completed the Delaware Basin Study to provide a roadmap for long-term transmission planning for the area.
- While the **Panhandle** had the highest congestion in ERCOT in 2019, the integration of Lubbock Power and Light in 2021 is expected to improve the ability to export generation from the region. However, the addition of generation between the Panhandle and the Dallas-Fort Worth area is expected to result in new transmission constraints.
- In **South Texas**, a significant amount of industrial load is developing along the coast. Additionally, a total of 6.5 GW of existing and planned wind and solar resources are located throughout the region. Both of these developments could drive the need for new transmission projects.
- More than 25 GW of wind and solar resources are expected to be connected in **West Texas** by 2021. Several recent studies indicate the potential for West Texas export constraints and the need to improve the transmission system.

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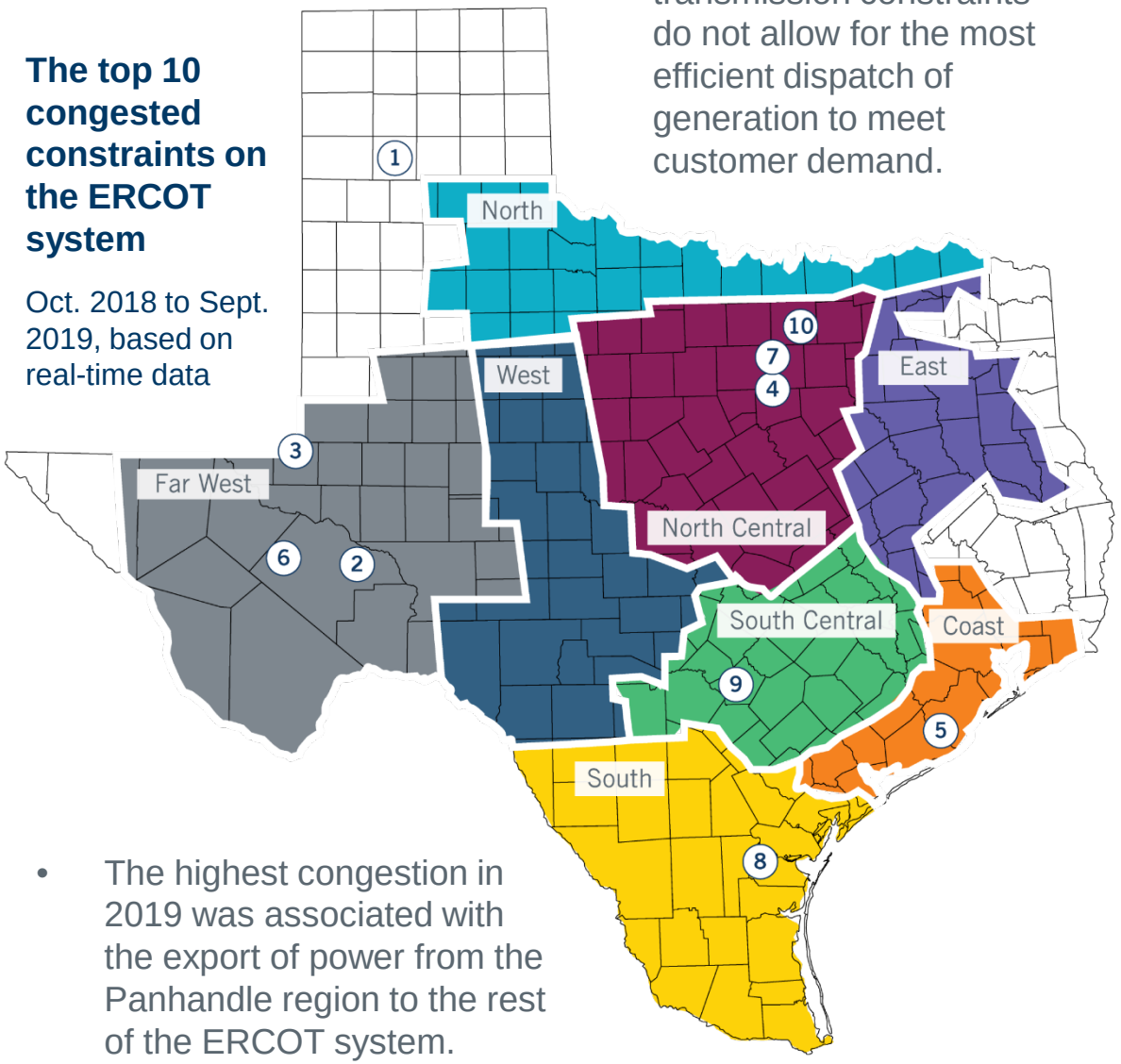
Recent Constraints

Map	Constraint	Congestion Rent
1	Panhandle Export	$55.5 M
2	Rio Pecos - 16th Street 138-kV Line	$53.2 M
3	Andrews County South - No Trees - Cheyenne Tap 138-kV Lines	$49.4 M
4	Everman Switch 345/138-kV Transformer	$41.4 M
5	South Texas Project - Jones Creek & Dow Chemical 345-kV Lines	$40.4 M
6	Fort Stockton Switch - Barrilla 69-kV Line	$33.9 M
7	Eagle Mountain SES - Saginaw Switch 138-kV Line	$28.4 M
8	Lon Hill 345/138-kV Transformer	$27.2 M
9	Marion - Hill Country 345-kV Line	$27.1 M
10	Jones Street - Lakepointe - Carrollton Northwest 138-kV Lines	$22.4 M

The top 10 congested constraints on the ERCOT system

Oct. 2018 to Sept. 2019, based on real-time data



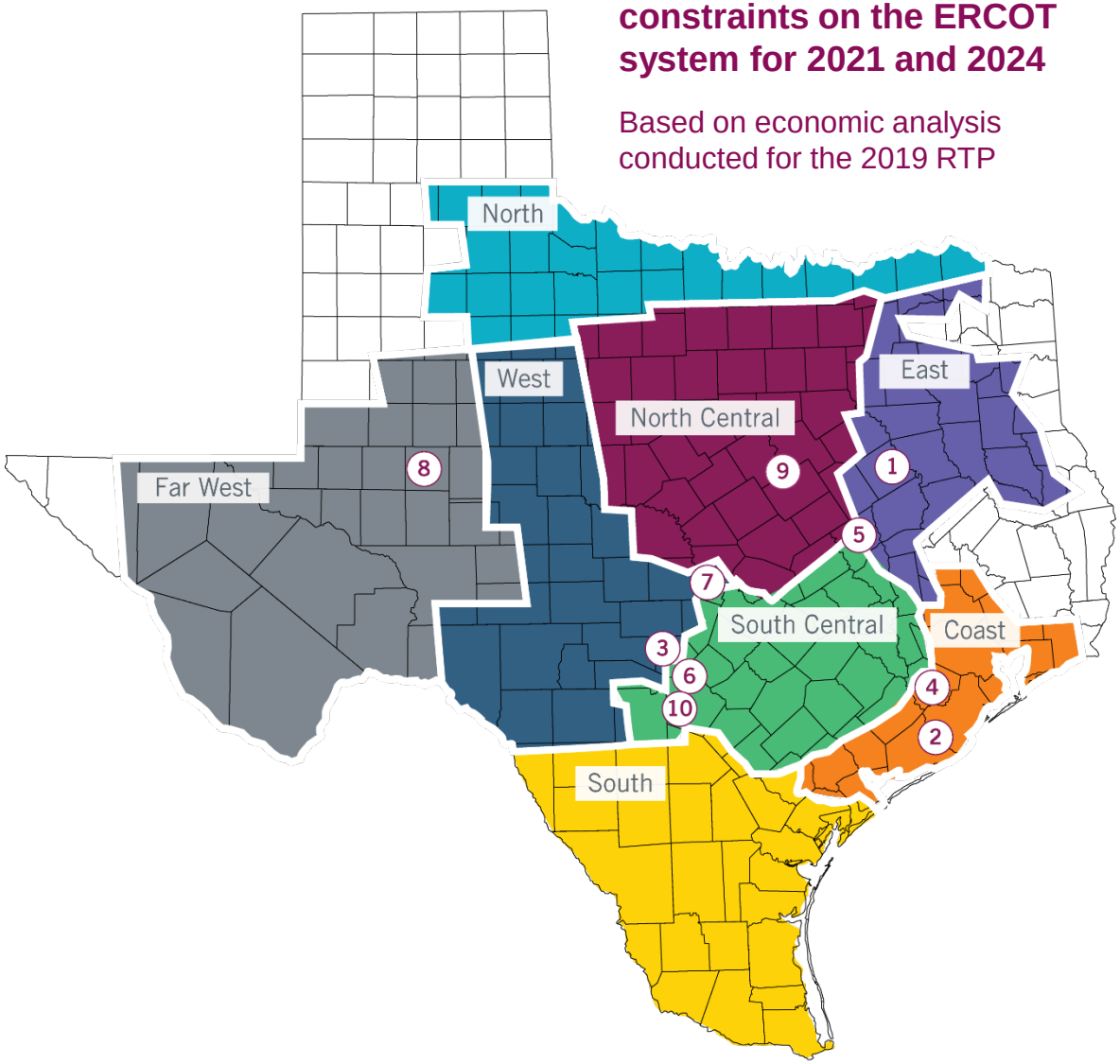
- Congestion occurs when transmission constraints do not allow for the most efficient dispatch of generation to meet customer demand.
- The highest congestion in 2019 was associated with the export of power from the Panhandle region to the rest of the ERCOT system.

Projected Constraints

Map	Constraint	Congestion Rent 2021	Congestion Rent 2024
1	Big Brown - Jewett 345-kV Line	$65.1 M	$72.8 M
2	South Texas - Jones Creek 345-kV Line	$123.8 M	$4.9 M
3	Kendall - Bergheim 345-kV Line	$42.6 M	$47.5 M
4	WA Parish - Oasis 345-kV Line	$48.9 M	-
5	Twin Oak - Jack Creek 345-kV Line	$3.3 M	$42.9 M
6	Bergheim 345/138-kV Transformer	$15.7 M	$26.3 M
7	Wirtz – Flat Rock 138-kV Line	$18.6 M	$19.1 M
8	Einstein - Carterville 138-kV Line	$32.2 M	-
9	Bosque Switch - Rogers Hill 138-kV Line	$14.0 M	$16.1 M
10	Kendall - Cagnon 345-kV Line	$17.6 M	$11.3 M

The top 10 projected constraints on the ERCOT system for 2021 and 2024

Based on economic analysis conducted for the 2019 RTP

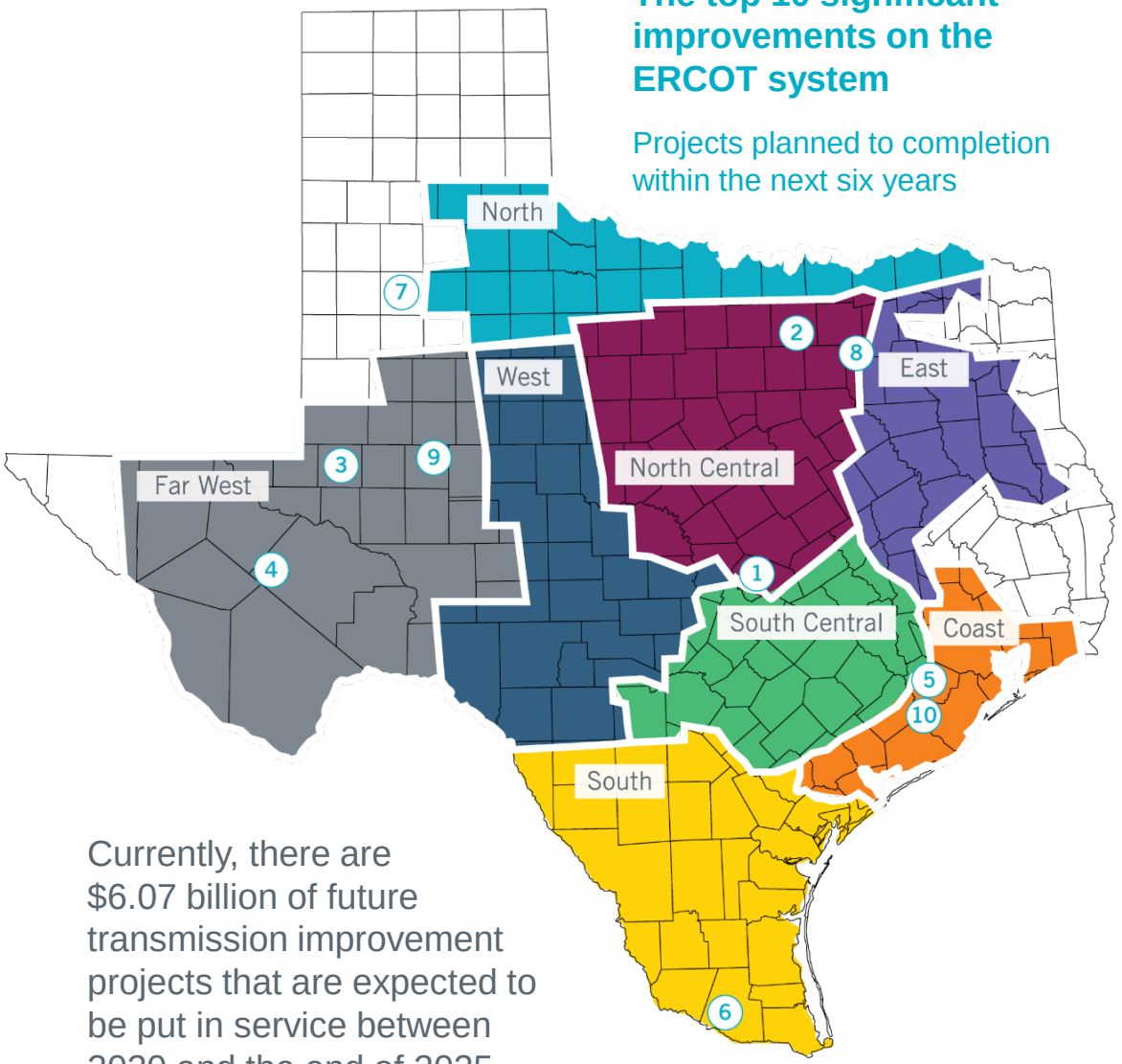


Planned Improvements

Map	Transmission Improvement	In-Service
1	New Leander – Round Rock 138-kV Line	2020
2	Upgrade Lewisville – Lakepointe 138-kV Line	2020
3	New Riverton – Odessa EHV/Moss 345-kV Line	2020
4	New Sand Lake – Solstice & Solstice – Bakersfield 345-kV Lines	2020
5	Convert Fort Bend – West Columbia 69-kV Line to 138 kV	2020
6	New Stewart Road 345-kV Station with 345/138-kV Transformers and Shunt Reactor	2021
7	New Ogallala – Abernathy, Abernathy – North, and Abernathy – Wadsworth 345-kV Lines	2021
8	Upgrade Royse – Forney 345-kV Line	2021
9	New Bearkat – Longshore 345-kV Line	2022
10	New Bailey – Jones Creek 345-kV Double-Circuit Line	2022

The top 10 significant improvements on the ERCOT system

Projects planned to completion within the next six years



Currently, there are $6.07 billion of future transmission improvement projects that are expected to be put in service between 2020 and the end of 2025.

Far West Load Growth

>600

Far West 2018-2019 Peak Load Growth (MW)

4,322

Far West 2019 Peak Load (MW), Exceeding 4,000 for the first time in June

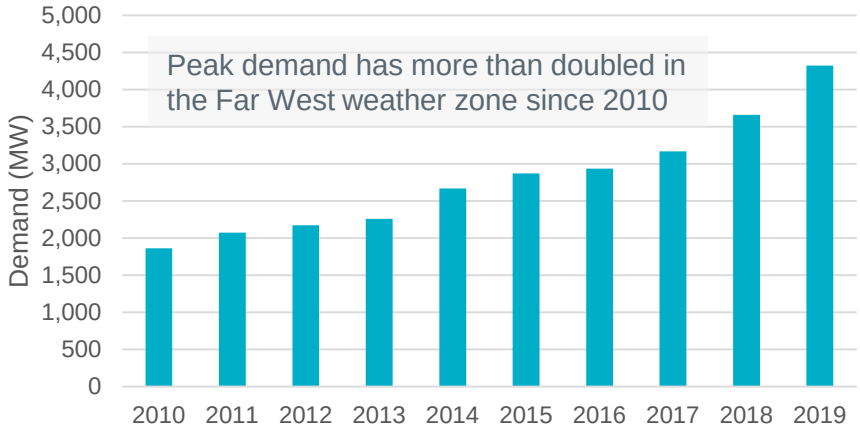
>10%

Far West 2010-2019 Annual Peak Load Growth Rate

~1.5%

ERCOT System-wide 2010-2019 Annual Peak Load Growth Rate

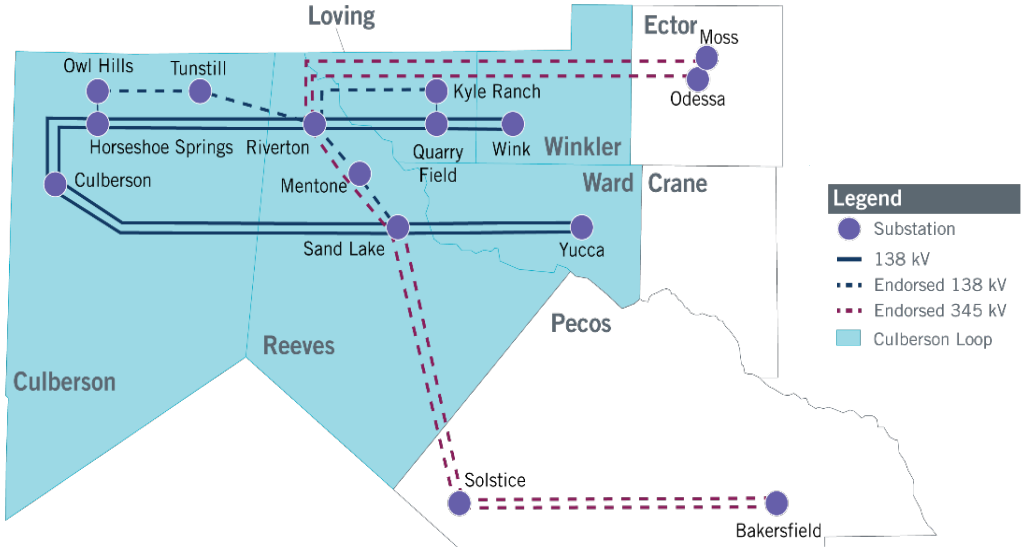
Far West Weather Zone Peak Demand



- Ensuring that the necessary transmission improvements are in place in time to serve the growing load has been a challenge because the nature of the industry is such that customers are not able to accurately project their demand needs more than one or two years ahead of time while transmission improvements can take up to six years to complete.
- Lagging infrastructure can contribute to customer connection delays, service quality issues, reliability and operating challenges, high congestion costs, and implementation of sub-optimal transmission solutions.
- ERCOT is working with stakeholders on process improvements to identify transmission project needs earlier and to shorten the review time for projects.

Far West Load Growth (Planned Improvement)

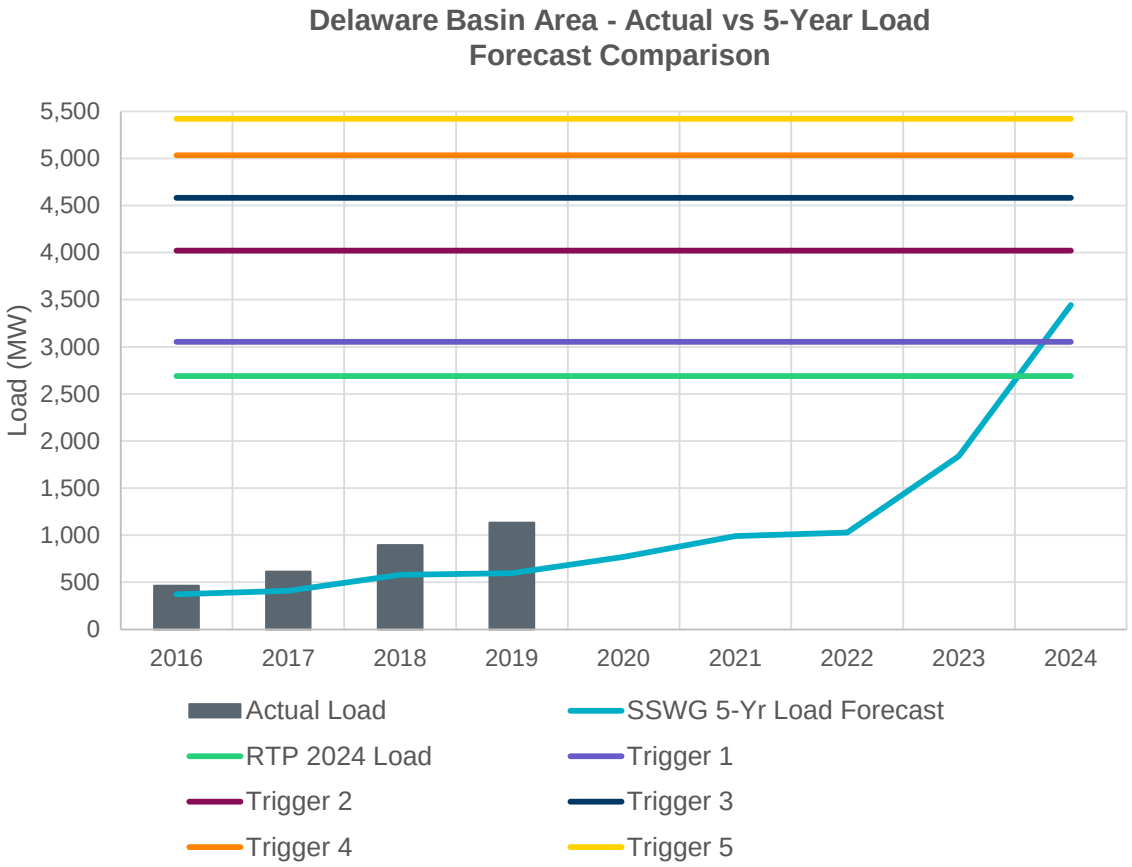
Several transmission improvement projects are underway to address congestion resulting from the significant load growth, especially in the Delaware Basin area.



Transmission Improvement Project	ERCOT Endorsement	Anticipated Service Date
Riverton-Sand Lake 138-kV line (new)	November 2016	December 2019
Far West Texas Project 1.0 (New Odessa-Riverton and Bakersfield-Solstice 345-kV lines)	June 2017	December 2020
Far West Dynamic Reactive Devices	June 2018	December 2019
Far West Texas Project 2.0 (New Riverton-Sand Lake-Solstice 345-kV line and Kyle Ranch-Riverton and Horseshoe Spring-Riverton 138-kV lines)	June 2018	May 2019~May 2021
Ward and Winkler County Transmission Improvement Project (Conversion of TNMP Wink to Pecos from 69kV to 138kV)	October 2019	December 2020
Wolf to Moss 138-kV Line High Temperature Upgrade	September 2019	March 2020

Far West Load Growth (Delaware Basin Study)

- The transmission improvements planned for Far West Texas are sufficient to meet the current load forecast of oil and gas development as studied in the 2019 Regional Transmission Plan (RTP). However, if load grows faster than anticipated, new projects will likely be needed.
- ERCOT, with extensive review and input by TSPs and stakeholders, performed a steady state reliability analysis using a higher-than-forecasted load growth in the Delaware Basin area to identify potential reliability needs and cost-effective bulk power system upgrades, particularly long lead time transmission improvements, which may be necessary if the load in the Delaware Basin area increases at a rapid pace.
- The results provide a roadmap for long-term transmission planning to the ERCOT stakeholders that includes the upgrade needs and the associated triggers in terms of load level in the Delaware Basin area.

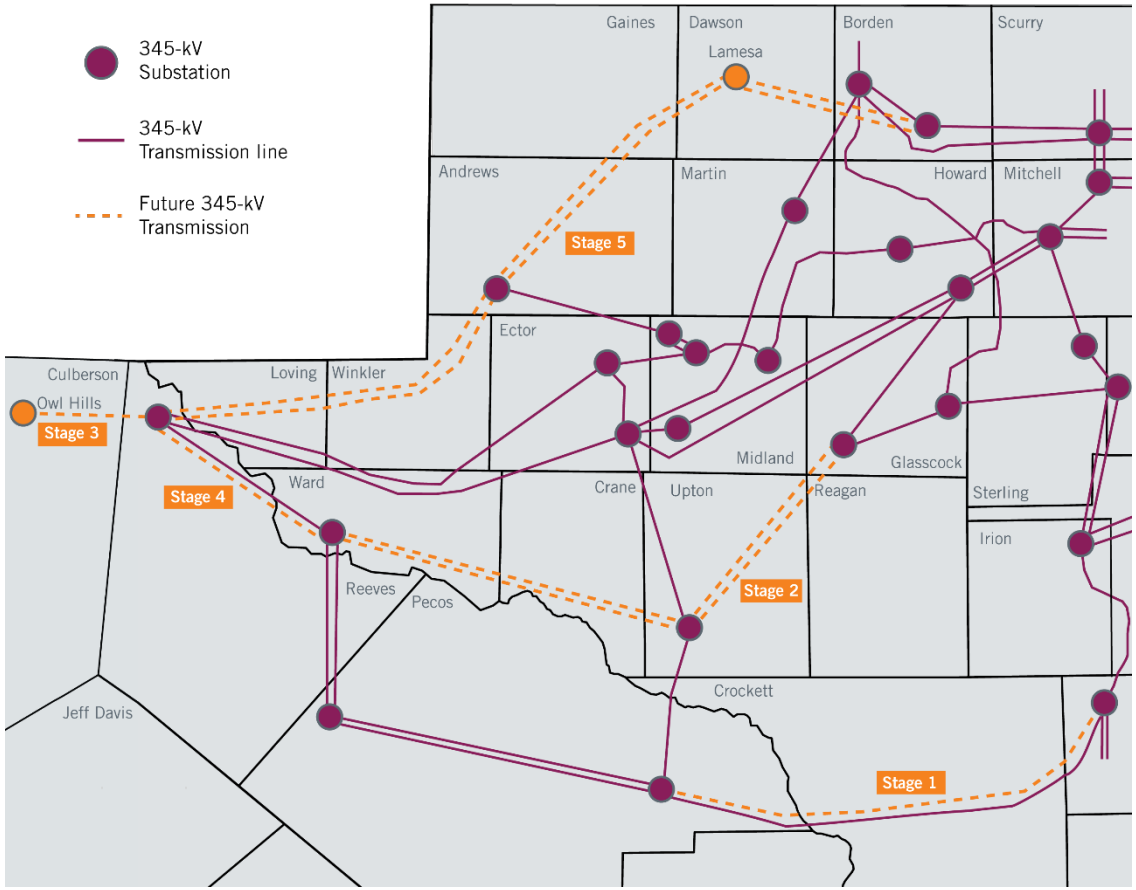


Far West Load Growth (Delaware Basin Study)

- It should be noted that the identified improvements were based on the assumptions used in the steady state analysis in this study. Should these assumptions change, the results of this analysis will need to be updated which could yield a different set of transmission improvements or trigger points.

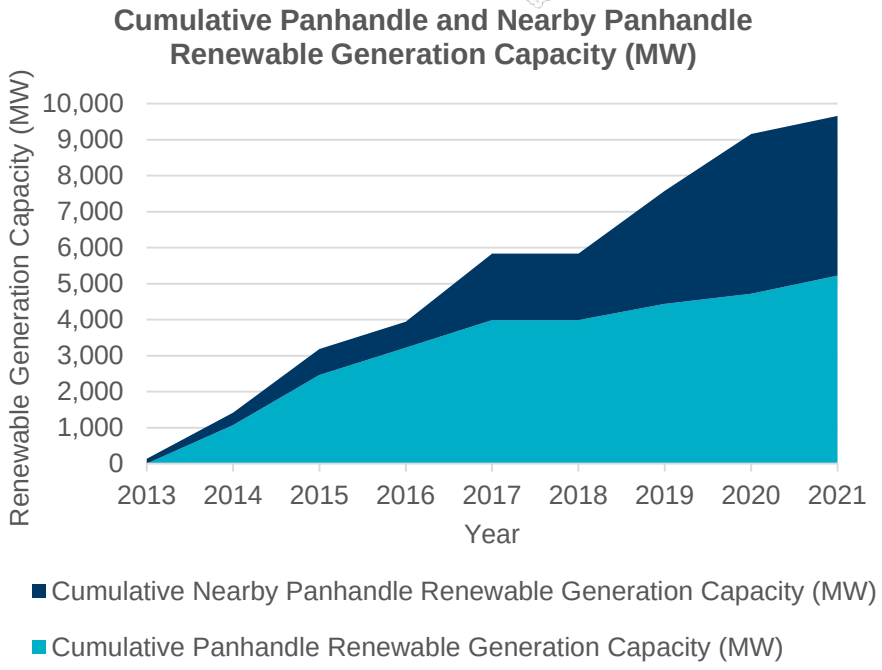
Delaware Basin transmission upgrade roadmap

Stage	Estimated Delaware Basin Load Level (MW)	Upgrade Element	Estimated Upgrade Cost ($M)
1	3,052	Add a second circuit on the existing Big Hill–Bakersfield 345-kV line	69
2	4,022	A new Bearkat–North McCamey– Sand Lake double circuit 345-kV line	371
3	4,582	A new Riverton–Owl Hills single circuit 345-kV line	41
4	5,032	Riverton–Sand Lake 138-kV to 345-kV conversion and a new Riverton–Sand Lake 138-kV line	56
5	5,422	A new Faraday–Lamesa–Clearfork–Riverton double circuit 345-kV line	444



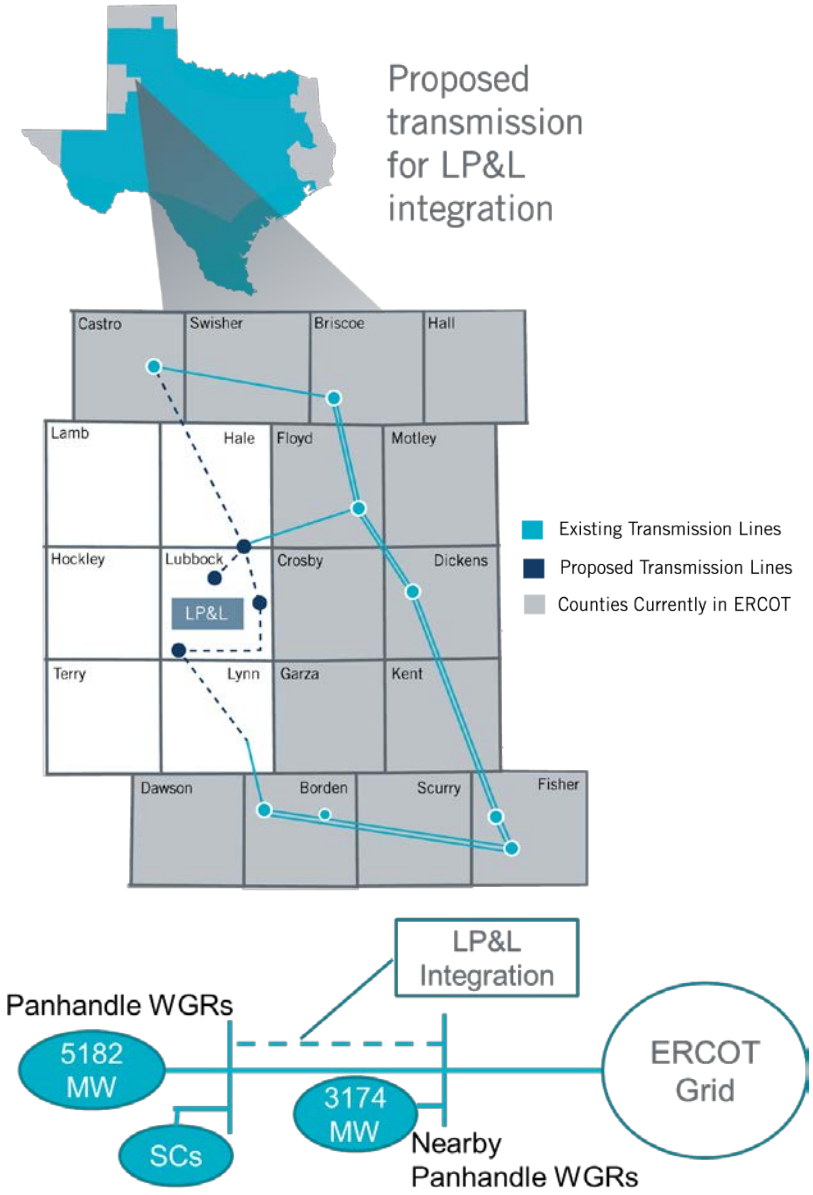
Panhandle Constraint

- ERCOT uses the Panhandle Generic Transmission Constraint (GTC) to manage the stability challenges associated with reliably exporting generation from the Panhandle region to the major load centers in Texas.
- Since the Panhandle GTC was established, it has been one of the top congested constraints in the ERCOT system and had the highest amount of congestion rent in 2019.
- Due to the implementation of transmission improvement projects in 2018 and the addition of generation between the Panhandle and Dallas-Fort Worth, also known as the “nearby” Panhandle region, the nature of the stability limitations is changing.
- ERCOT is evaluating new tools for managing the stability limit in real-time and whether the Panhandle GTC interface definition should change.



Panhandle and Lubbock Load Integration

- Transmission upgrades for the Lubbock Power and Light (LP&L) integration are scheduled for completion in June 2021.
- The LP&L integration project will provide an additional 345-kV path to export power from the Panhandle.
- In 2019, ERCOT conducted a Panhandle stability study including the existing and committed wind generation (WGR) in the Panhandle and nearby Panhandle regions.
- Findings from the 2019 study include:
  - The system experienced improved stability with the LP&L system integrated.
  - Voltage instability and inter-area oscillation are expected to be the most limiting constraints under outage conditions.
- ERCOT will continue to monitor renewable generation development in the Panhandle and nearby Panhandle regions and assess system stability constraints as they evolve.



West Texas Export

Competitive Renewable Energy Zone reactive compensation plan was designed to accommodate **14 GW** of West Texas renewable generation

2013

>25 GW of renewable generation is expected to be connected in West Texas

2021

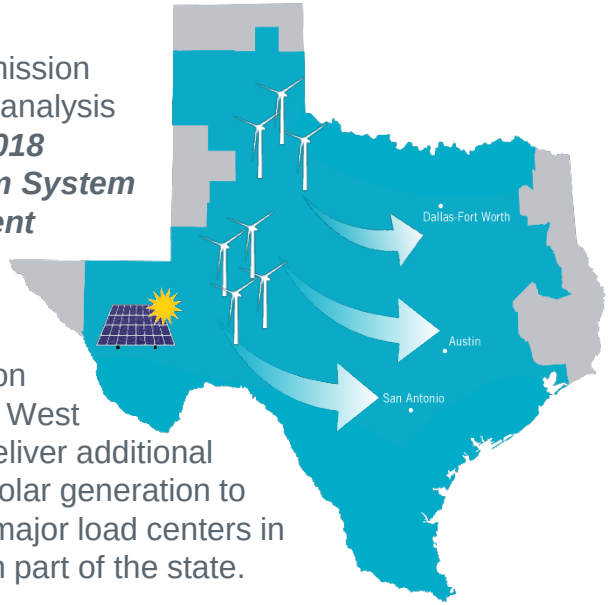
2012	10 MW
2014	32 MW
2016	296 MW
2018	1,325 MW
2020	4,246 MW
2021	7,010 MW

West Solar

2012	8,220 MW
2014	8,634 MW
2016	9,842 MW
2018	11,606 MW
2020	13,335 MW
2021	18,687 MW

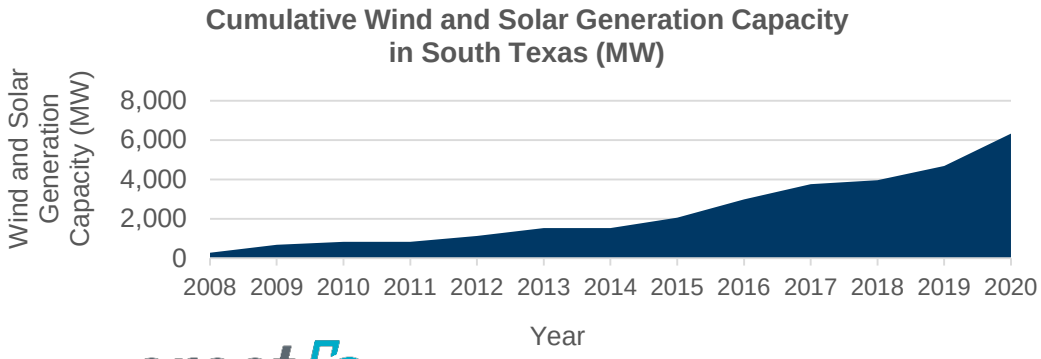
West Wind

- Several recent studies have indicated the potential for West Texas export constraints and the need to improve West Texas transmission to accommodate the increasing addition of renewable generation:
  - The ***2018 Dynamic Stability Assessment of High Penetration of Renewable Generation in the ERCOT Grid*** indicated that an additional transfer path between West Texas and Central Texas can be beneficial from a stability perspective.
  - The ***2019 Regional Transmission Plan*** identified high amounts of congestion on the Kendall – Cagnon and Kendall – Bergheim 345 kV circuits (see slide 5). This congestion primarily resulted from an increase in wind and solar generation in the west and north regions of ERCOT.
  - The transmission expansion analysis from the ***2018 Long-Term System Assessment*** identified a need for additional transmission paths from West Texas to deliver additional wind and solar generation to ERCOT's major load centers in the eastern part of the state.



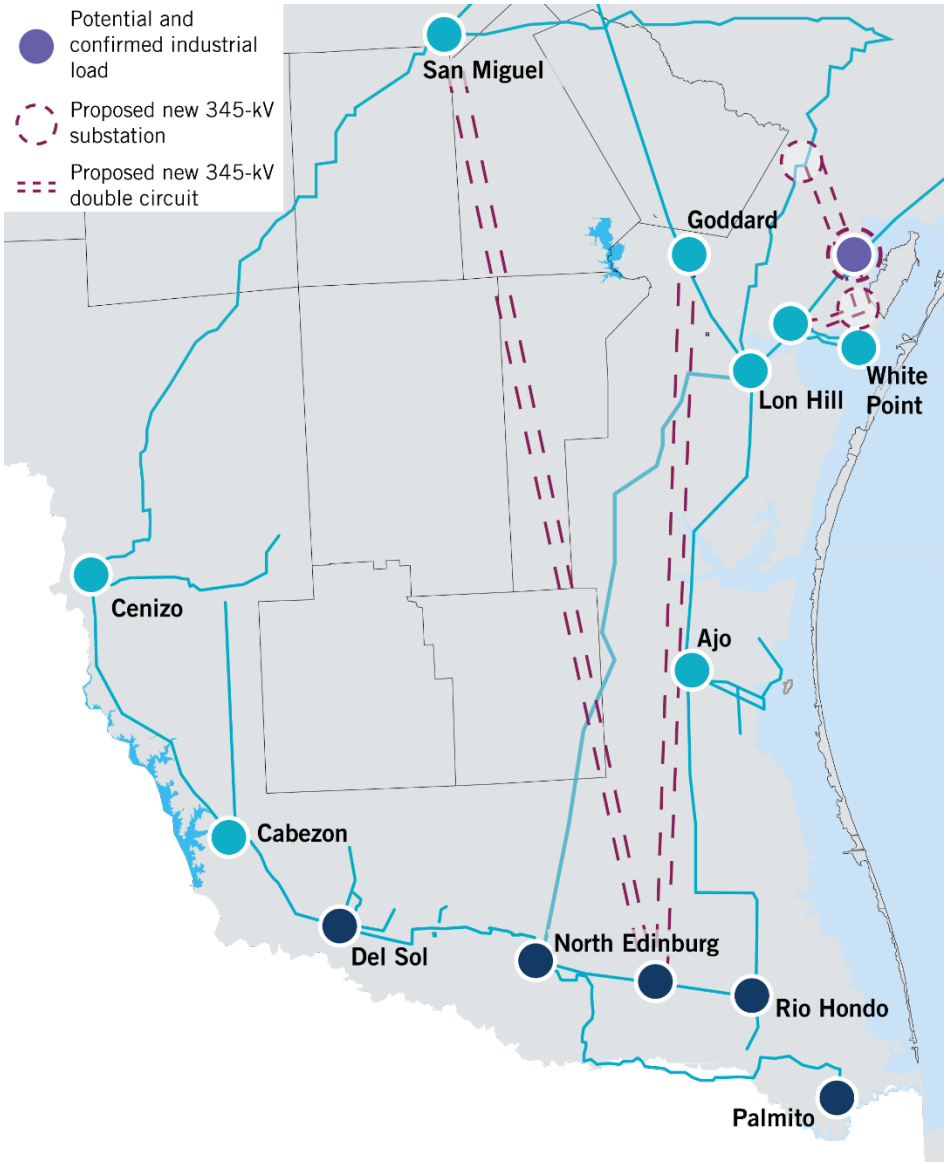
South Texas

- ERCOT has experienced a substantial amount of wind and solar generation development activity in South Texas, including the Lower Rio Grande Valley (LRGV), in recent years.
- Transmission reliability studies have identified multiple stability constraints within the South Texas region. In fact, five of the existing ten GTCs (GTCs are used to manage stability constraints in operations) are located in South Texas.
- As generation development continues in the region, ERCOT will perform system reliability analysis, evaluate tools to manage the constraints, and evaluate transmission projects to cost-effectively mitigate the constraints.



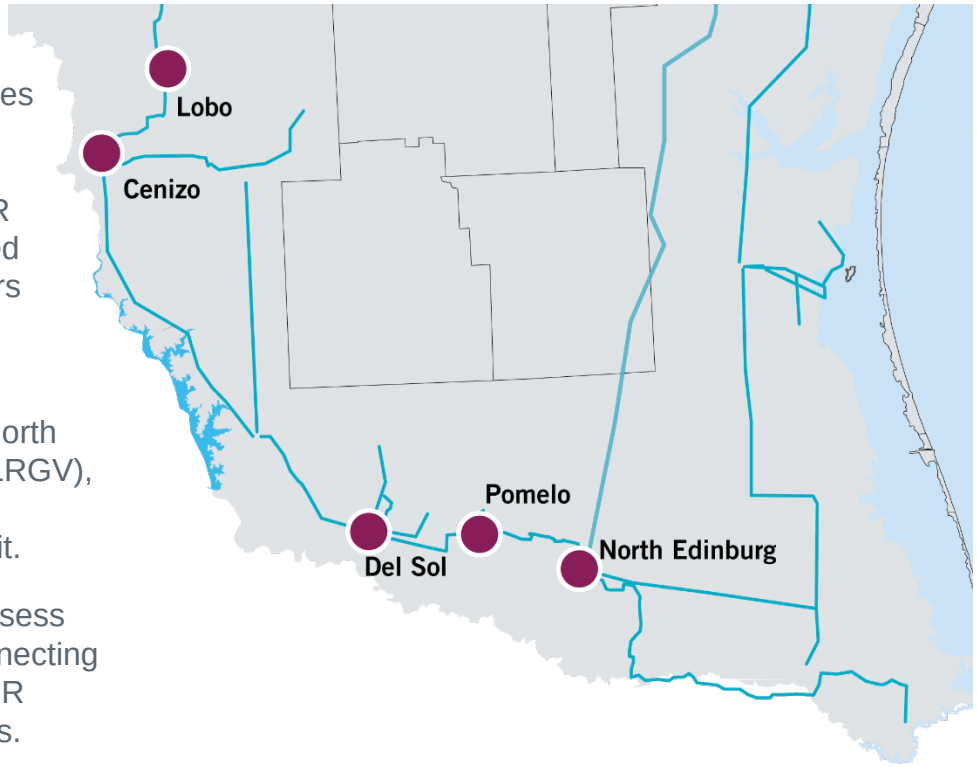
South Texas

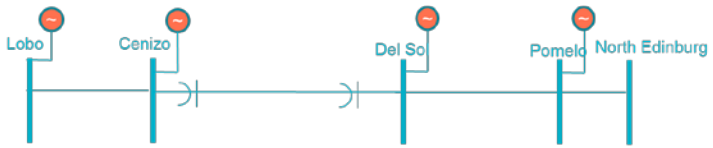
- To serve potential industrial load additions in South Texas, three transmission improvement projects were proposed in 2018 and 2019:
  1. In January 2018, AEPSC submitted the Lower Rio Grande Valley (LRGV) Import Project to address the native LRGV load growth and the addition of potential Liquefied Natural Gas (LNG) load.
  2. In May 2019, STEC submitted the LRGV Transmission Expansion Project to address the addition of potential LNG load.
  3. In September 2019, AEPSC submitted the Corpus North Shore Project to address reliability needs primarily driven by industrial load additions in the Corpus Christi area.
- ERCOT is currently evaluating the need for these projects.



Subsynchronous Resonance

- Series capacitors are implemented to improve the transfer capability across the transmission system without adding new circuits. However, series capacitors can induce subsynchronous resonance (SSR) which can cause fast, unstable oscillations between generation and transmission circuits. SSR must be evaluated and mitigated to avoid undesired generation trips and potential damage to generators and series capacitors.
- Since the 2016 completion of the series capacitor compensated circuit from the Lobo station to the North Edinburg station in the Lower Rio Grande Valley (LRGV), more than 2 GW of wind and solar generation has connected to or is planning to connect to this circuit.
- Advanced modeling and studies are required to assess the potential for SSR in this area. Generators connecting to this transmission line are required to provide SSR mitigation by precise tuning of their control systems.
- If more generation projects are to connect to this transmission line, the SSR mitigation provided by the generators alone may not be sufficient to prevent SSR and transmission system improvements could be needed.





Renewable Generation Capacity Connected to the Lobo-North Edinburg 345-kV circuit	
Cumulative Installed	1638 MW
Planned and Financially Committed	403 MW
Additional Potential Generation Under Study	> 2000 MW

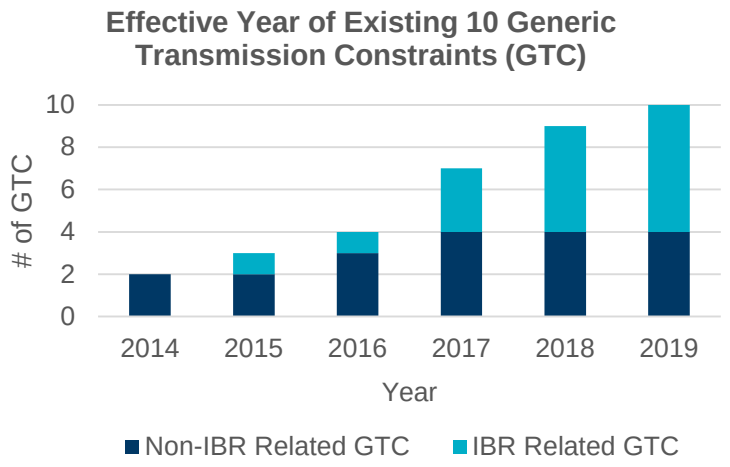
Evolving Grid with Inverter-Based Resources

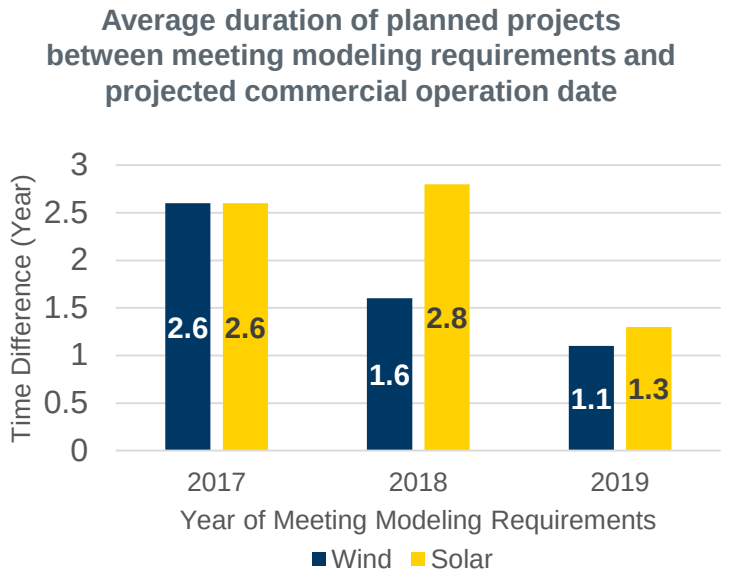
- Inverter-based resources (IBRs) are generators that are connected to the power system either completely or partially through a power electronic converter interface. IBRs include wind, solar PV, and battery

18-24 Months
Typical time for IBRs from initial planning to physical interconnection

0
Number of IBRs currently planned beyond 2022

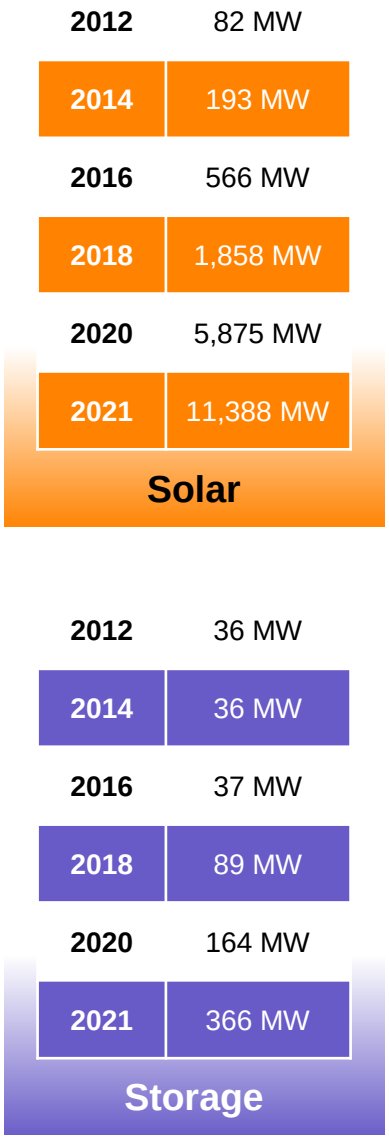
- Increasing IBR challenges for planning assessments:
  - Peak and off-peak may no longer represent the most stressed system condition to assess. With increasing IBRs in the system, more scenarios, like high IBR conditions also impose system challenges, especially voltage and stability issues, leading to more GTCs.
  - Identified transmission improvements may not be optimal due to the lack of long term generation commitment.
  - Reliability issues like stability limits are being identified late in the process and GTCs will be needed before system improvements can be implemented.

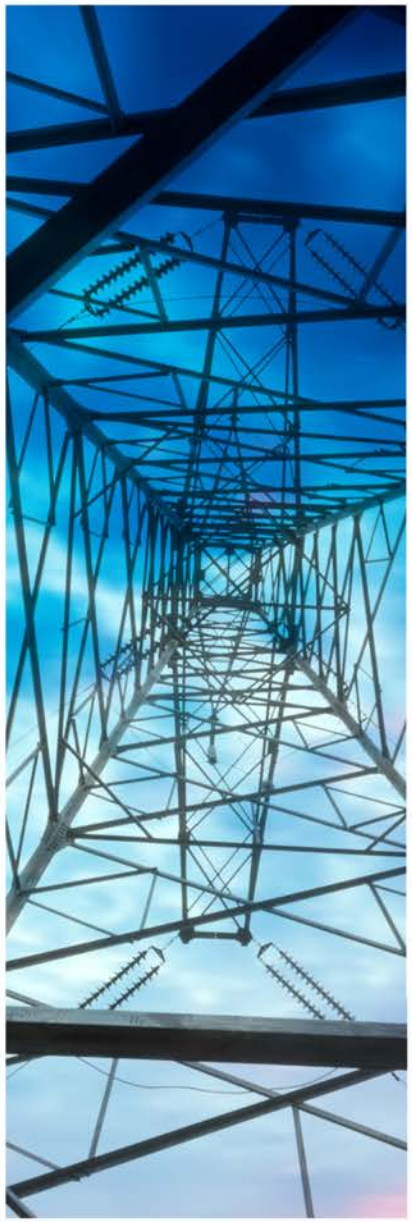




Evolving Grid with Inverter-Based Resources

- With the continuous growth of renewable generation it is possible that the total installed renewable generation capacity could reach 47 GW (~35.8 GW wind and ~11.4 GW solar) by 2021.
- In addition, ~4 GW energy storage projects are in the interconnection study process to connect to the ERCOT grid and ~4 GW of potential projected rooftop PV are currently considered in the 2020 Long-Term System Assessment.
- In the future, the ERCOT grid may no longer be comprised mainly of synchronous generators, such as coal and natural gas plants. Already there have been times when system demand is being served by a greater percentage of IBRs than synchronous generators.
- IBRs have a different response to disturbances on the system when compared to synchronous generators due to the fundamental differences in the way power is produced.
- ERCOT may need to implement new requirements for IBRs to ensure reliable operation.





Appendix

About ERCOT Transmission Planning

ERCOT supervises and exercises comprehensive independent authority over the planning of transmission projects for the ERCOT system as outlined in PURA and Public Utility Commission of Texas (PUCT) Substantive Rules. The PUCT Substantive Rules further indicate that the independent organization (IO) shall evaluate and make a recommendation to the PUCT as to the need for any transmission facility over which the IO has comprehensive transmission planning authority. ERCOT examines the need for proposed transmission projects based on ERCOT planning criteria and NERC Reliability Standards. Once a project need has been identified ERCOT evaluates project alternatives based on cost-effectiveness, long-term system needs and other factors.

The ERCOT Nodal Protocols and Planning Guide describe the practices and procedures through which ERCOT meets its requirements related to system planning under PURA, PUCT Substantive Rules, and North American Electric Reliability Corporation (NERC) Reliability Standards.

ERCOT annually performs a planning assessment of the transmission system that is primarily based on three sets of studies:

- The Regional Transmission Plan (RTP) addresses region-wide reliability and economic transmission needs and includes the recommendation of specific planned improvements to meet those needs for the upcoming six years. The public version of the 2019 RTP report is posted on the ERCOT website at: http://www.ercot.com/news/presentations/.
- The Long-Term System Assessment (LTSA) uses scenario-analysis techniques to assess the potential needs of the ERCOT system up to 15 years into the future. The role of the LTSA is to provide a roadmap for future transmission system expansion and identify long-term trends that should be considered in near-term planning. The biennial LTSA study is conducted in even-numbered years. The 2018 Long-Term System Assessment report is posted on the ERCOT website at: http://www.ercot.com/news/presentations/.
- Stability studies are performed to assess the angular stability, voltage stability, and frequency response of the ERCOT system. Due to the security-related sensitive nature of the information contained in these study reports, they are not published on the ERCOT website.

Contacts and Links

Contacts and Information

For general communications and queries, the public can submit an information request at:
http://www.ercot.com/about/contact/inforequest

Media

Leslie Sopko

512-275-7432

Regulatory and Government Relations

Lindsey Hughes

512-225-7177

Internet Links

ERCOT website: http://www.ercot.com

Market Information System:
https://mis.ercot.com/pps/tibco/mis

Users must obtain a digital certificate for access to this area. Folders in this area include data, procedures, reports and maps for both operations and planning purposes. Helpful information that can be found on this site includes the following:

- Generation Project Interconnection Information
- Regional Planning Group Information
- Steady-State Base Cases