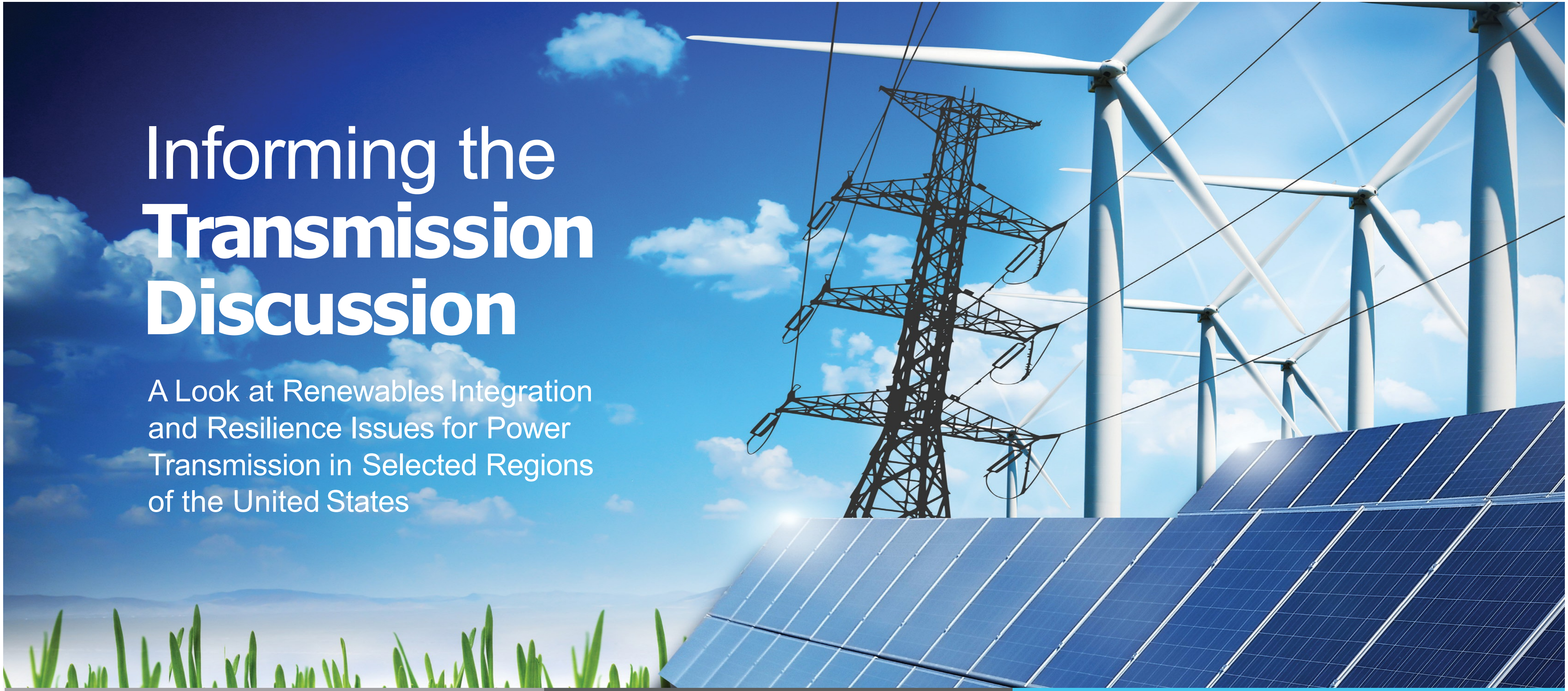


Informing the **Transmission Discussion**

A Look at Renewables Integration and Resilience Issues for Power Transmission in Selected Regions of the United States

January 2020

scottmadden
MANAGEMENT CONSULTANTS

WIRES®

Regional Discussion

MIDCONTINENT ISO

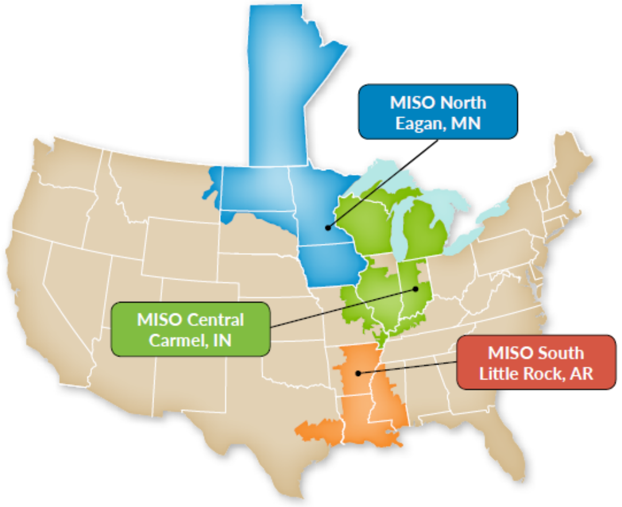
Contents

Overview

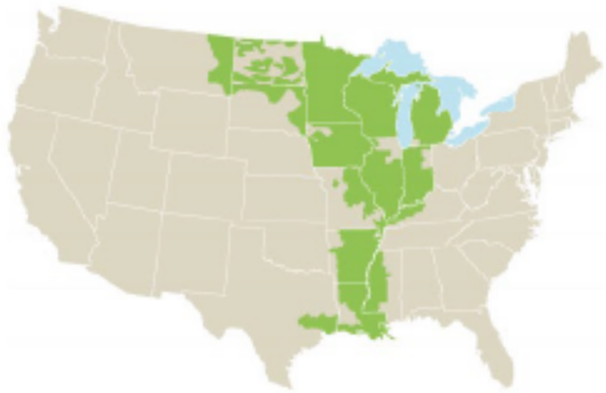
- The Midcontinent ISO (MISO) footprint covers about 900,000 square miles and encompasses all or parts of 15 states (and the province of Manitoba).
- Wind penetration in MISO has increased significantly, with 19 GWs of registered in-service capacity.
- In its latest transmission plan, MISO projects thermal generation retirements of about 3.8 GWs in 2018 and 0.4 GWs in 2019.

Key Regional Statistics	
States Covered	AR, IA, IL, IN, KY, LA, MI, MN, MO, MS, MT, ND, SD, TX, WI
Square Mi. Covered	~900,000
No. of Utilities	51 transmission owner-members; 37 local balancing authorities
No. of Customers/Pop. Served	~42MM people served
Installed Capacity	175,528 MWs (market); 190,432 MWs (reliability)
Transmission Line Miles	71,800 miles
Peak Hour Demand (all time)	Summer: 127,125 MWs (market), 130,917 MWs (reliability) Winter: 109,336 MWs (market), 117,903 MWs (reliability)
Net Energy for Load (2018)	683,593 GWhs
Forecast Growth (Annual)	0.3% peak load growth† 0.5% energy growth

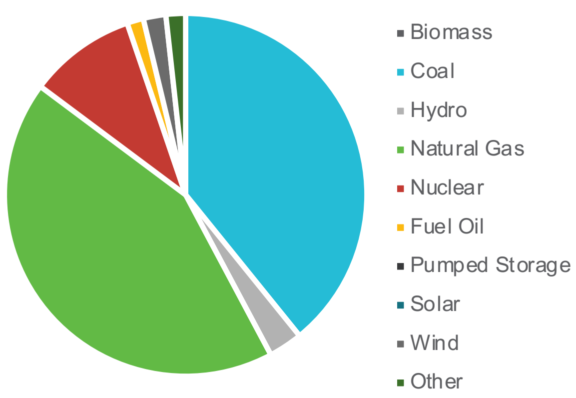
MISO's Reliability Footprint and Locations of Regional Control Centers



MISO's Market Footprint

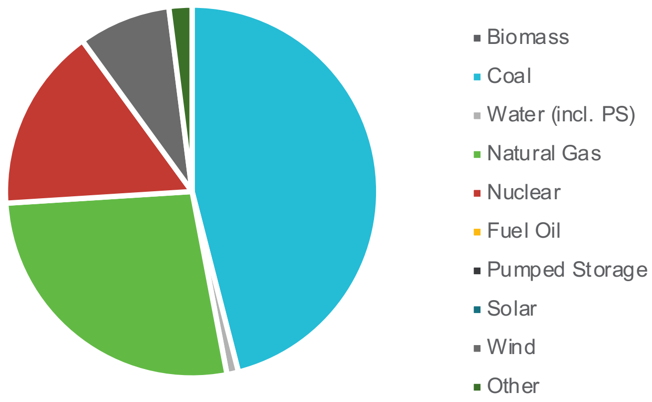


2018 Capacity Mix by Fuel



Source: MISO 2018 SOM

2018 Energy Mix* by Fuel

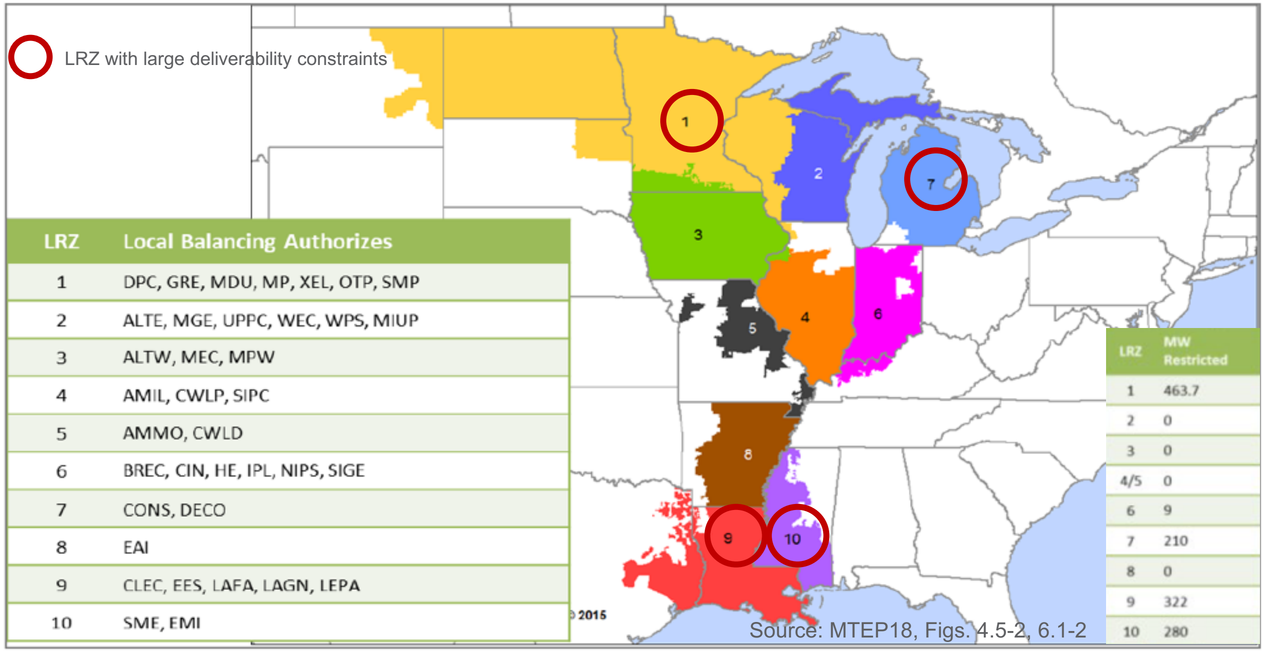


Source: MISO 2018 SOM

Sources: NERC 2018 LTRA; MISO Fact Sheet; NERC ES&D (net energy for load); MTEP18; MISO 2018 SOM
Notes: Peak-load statistics and forecasts are coincident unless otherwise indicated. Capacity shown is unforced capacity.

Overview (Cont'd)

MISO's Local Resource Zones, Balancing Authorities, and Resource Deliverability Constraints



LRZ	Local Balancing Authorizes
1	DPC, GRE, MDU, MP, XEL, OTP, SMP
2	ALTE, MGE, UPPC, WEC, WPS, MIUP
3	ALTW, MEC, MPW
4	AMIL, CWLP, SIPC
5	AMMO, CWLD
6	BREC, CIN, HE, IPL, NIPS, SIGE
7	CONS, DECO
8	EAI
9	CLEC, EES, LAFA, LAGN, LEPA
10	SME, EMI

LRZ	MW Restricted
1	463.7
2	0
3	0
4/5	0
6	9
7	210
8	0
9	322
10	280

Source: MTEP18, Figs. 4.5-2, 6.1-2

- For determination of resource adequacy, MISO is comprised of local resource zones (LRZs)* (see map at left).
- To evaluate resources (supply and demand-side resources) sufficient for reliability, for each planning year, MISO determines a per unit zonal local reliability requirement for each LRZ. This is defined as the amount of resources a particular area needs to meet the loss of load planning criteria of one day in 10 years without the benefit of importing capacity.
- In the near term, some restrictions on deliverability of resources are in the northern regions (more wind capability) and in the south (more gas-fired generation).
- Because of the diversity (population size, economic factors, weather patterns, retail electric sales, programs like energy efficiency) and geographic breadth of the MISO footprint, the LRZs also serve as sub-regional proxies for load (GWhs) and non-coincident peak load (GWs) growth and for wind capacity credits.

	LRZ1	LRZ2	LRZ3	LRZ4	LRZ5	LRZ6	LRZ7	LRZ8	LRZ9	LRZ10
Energy and Peak Demand Annual Growth Forecasts (2019–2028)										
Energy Growth (with EE adjustments)* (%)	0.95	.063	.087	0.06	0.20	1.03	0.22	0.70	0.59	1.46
Peak Demand (summer non-coincident without EE adjustment)** (%)	1.07	0.97	1.37	0.45	0.42	1.09	0.38	1.08	0.63	1.46
Import and Export Limits										
Capacity Import Limits**	4,415	2,595	3,369	6,411	4,332	7,941	3,785	4,834	3,622	2,688
Capacity Export Limits**	516	2,017	5,430	4,280	2,122	3,249	2,578	2,424	2,149	1,824

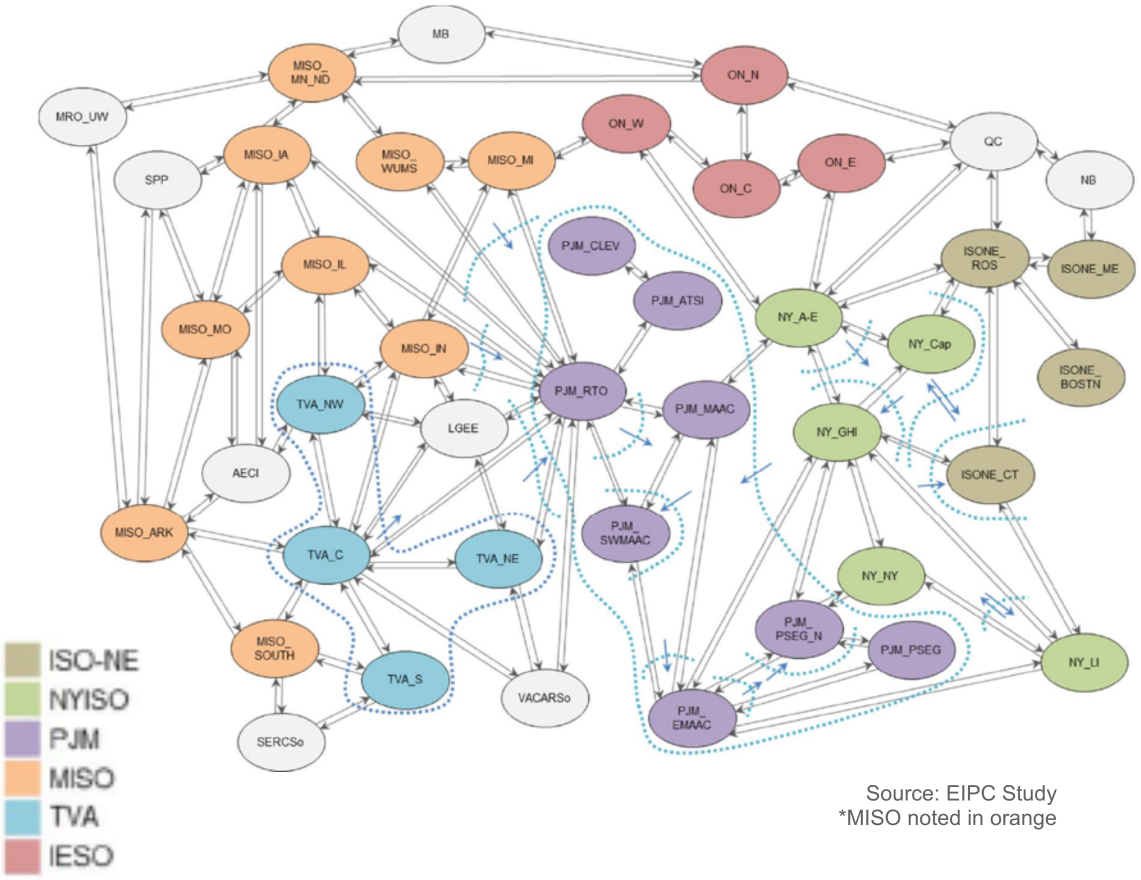
*GWh **MWs

Notes: *Local Resource Zones are geographic regions established based upon: (1) the electrical boundaries of local balancing authorities; (2) state boundaries; (3) the relative strength of transmission interconnections between local balancing authorities; (4) the results of loss of load expectation studies; (5) the relative size of LRZs; and (6) natural geographic boundaries such as lakes and rivers.

Sources: MTEP18; MISO LRZ Forecast; MISO Tariff, sec. 68A.3.

Transmission Topography and Investment

MISO Transmission Topography and Interconnections*



Source: EIPC Study
*MISO noted in orange

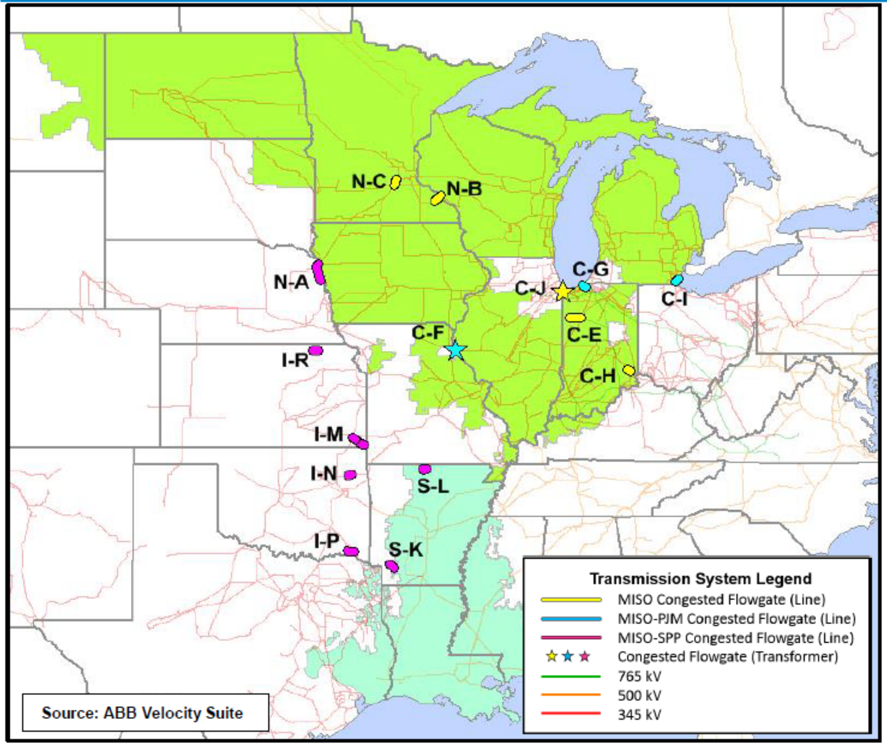
- MISO has an extensive transmission network, reaching from Canada to Texas, with nearly 24,480 miles of transmission 230 kV or above (34% of its system).
- Its region is bounded by the Southwest Power Pool (SPP) to the west, SERC to the southeast, the PJM Interconnection to the east, and the Independent Electricity System Operator of Ontario to the north.
- It has expanded over the past 20 years. Formed in 1998 and initially covering the upper Midwest of the United States, MISO has added transmission owners over time. It became the first FERC-approved RTO in December 2001. In December 2013, 10 transmission-owning companies (including the Entergy system) joined MISO to form the MISO South region.
- MISO is the sole-balancing authority for the region, executed through three regional control centers (see previous page).
- Historically, the majority of MISO North and MISO Central regions' dispatched generation comes from coal, while in MISO South gas is the primary dispatched generation. Gas-fired units set the system-wide price in 53% of hours in 2018, including almost all-peak hours. After the integration of MISO South, the percentage of generation from coal units began to decrease, and the integration of the region aids in fuel diversity.
- North-south intra-market flows between MISO Midwest (Central/North) and MISO South are limited under a settlement agreement with SPP. North-to-south flows are limited to 3 GWs (1 GW firm/2 GWs non-firm, as available). South-to-north flows are limited to 2.5 GWs (1 GW firm/1.5 GWs non-firm, as available).
- Transmission flows are generally characterized by increasing west-to-east flows, as higher levels of wind resources mean higher generation and capacity resources in western and central MISO than in the eastern part of the Midwest region.

Sources: EIPC Study; MISO, "Celebrating 15 Years of Regional Transmission Services," available at http://timeline.misomatters.org/ (accessed Aug. 1, 2019); 2018 SOM; Jan. 2018 Event Report; DOE 2015 Congestion Study

Transmission Topography and Investment (Cont'd)

- As part of its current transmission expansion planning process, MISO has identified and is considering enhancements to its top congested flowgates, both within the region and with adjacent regions.
- As shown on the map at the right, top internal congested flowgates are in the upper Midwest (especially Minnesota) and lower Midwest (principally Indiana, near PJM).
  - Minnesota area congestion is largely driven by wind generation in LRZs 1–3.
  - Lower Midwest congestion (esp. C–F and C–G) is driven by generator retirements.

MTEP19 Market Congestion Planning Study Top Congested Flowgates



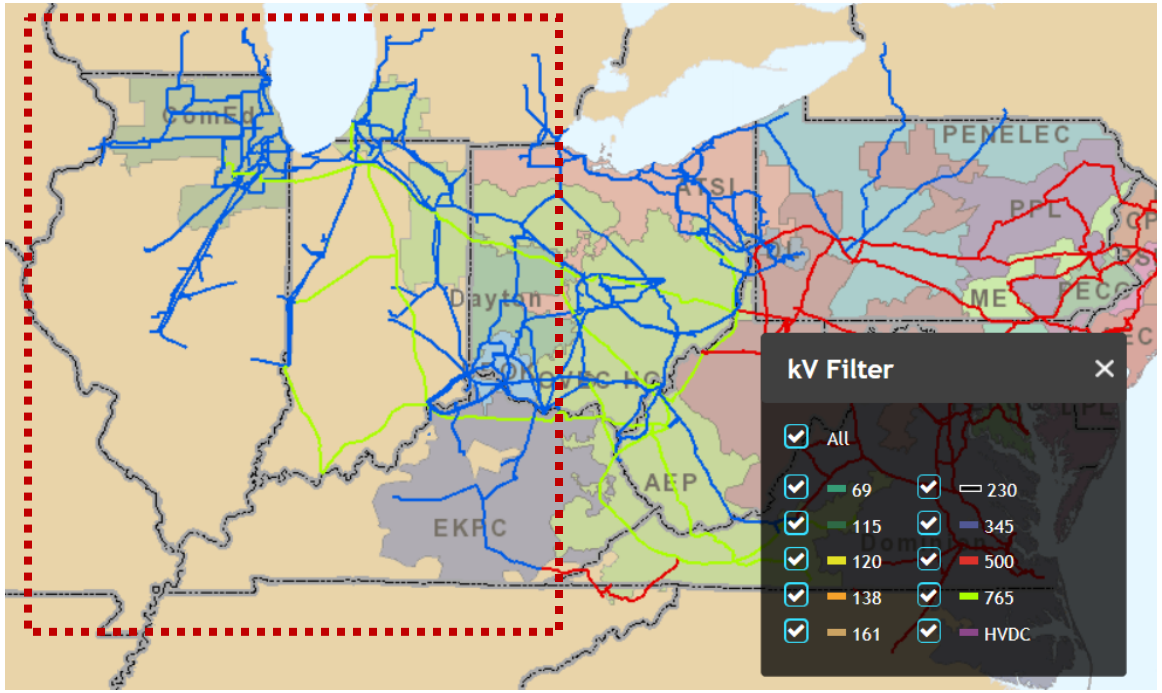
ID	Monitored Element	Area	Focus
N-A	Raun to Tekamah 161kV	MEC-NPPD	N/C, MISO-SPP
N-B	Wabaco to Alma 161kV	DPC	N/C
N-C	Helena to Scott County 345kV	NSP	N/C
C-E	Goodland to Reynolds 138kV	NIPS	N/C
C-F	Marblehead N Transformer 161/138kV	AMIL	N/C, MISO-PJM
C-G	Bosserman to Trail Creek 138kV	NIPS-AEP	N/C, MISO-PJM
C-H	Hubble to Batesville 138kV	HE-DUK-IN	N/C
C-I	Lallendorf to Monroe 345kV	FE-ATSI - DECO	N/C, MISO-PJM
C-J	Munster Transformer 345/138kV	NIPS	N/C
S-K	Fulton to Patmos 115kV	EES-AR	South, MISO-SPP
S-L	Bull Shoals to Midway Jordan 161kV	EES-AR	South, MISO-SPP
I-M	Neosho to Riverton 161kV	SPP	MISO-SPP
I-N	Kerr to Maid 161kV Ckt 2	SPP	MISO-SPP
I-P	Hugo to Valliant 138kV	SPP	MISO-SPP
I-R	Marshall to Smittyville 115kV	SPP	MISO-SPP
RDT	North – South Interface	MISO	N-S Interface

Source: MISO July 25 MCPS

Source: July 25 MCPS

Transmission Topography and Investment (Cont'd)

MISO-PJM Transmission System Interfaces



MSO/PJM interface area

Source: PJM

- The region is characterized by transmission seams to the west (with SPP) and to the east (with PJM). On its western boundary with SPP, MISO has 171 tie lines in voltages ranging from 69 kV to 500 kV (see table below). To the east, MISO has 146 interties with PJM.
- Imports and exports have 12 interfaces with a total interface capability of 14 GWs. Interface prices play a major role in deciding whether to schedule imports and exports with adjacent areas. MISO is typically a net importer, most actively scheduling with PJM. In 2018, total day-ahead and real-time net imports averaged 4.2 GWs and 4.8 GWs, respectively, with average hourly real-time imports from PJM of 1.9 GWs. However, on average, MISO's system marginal price was almost 20% lower than PJM's suggesting that MISO should be exporting to PJM.
- MISO has joint-operating agreements with PJM and SPP, allowing it to engage in market-to-market coordination. This allows redispatch from the other RTO's units to manage congestion if less costly than its own redispatch. MISO and PJM are also pseudo-tied; this allows each RTO to control capacity in the other. Through this mechanism, increasing amounts of capacity have been exported to PJM.

SPP-MISO AC Ties	
Voltage Level (kV)	**# of Tie-Lines**
69	78
115	28
138	4
161	24
230	20
345	14
500	3
Total	171

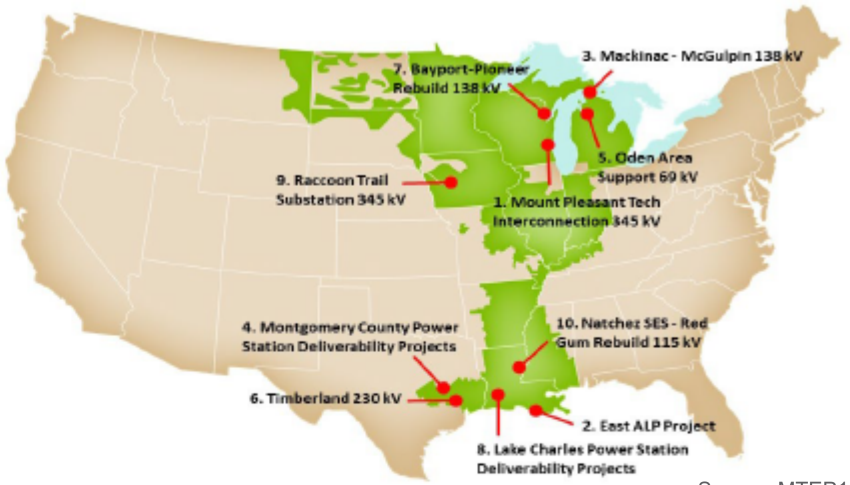
Source: OMS-RSC Seams White Paper

Sources: MISO 2018 SOM; PJM mapping (at https://gis.pjm.com/esm/default.html); OMS-RSC Seams White Paper

Transmission Topography and Investment (Cont'd)

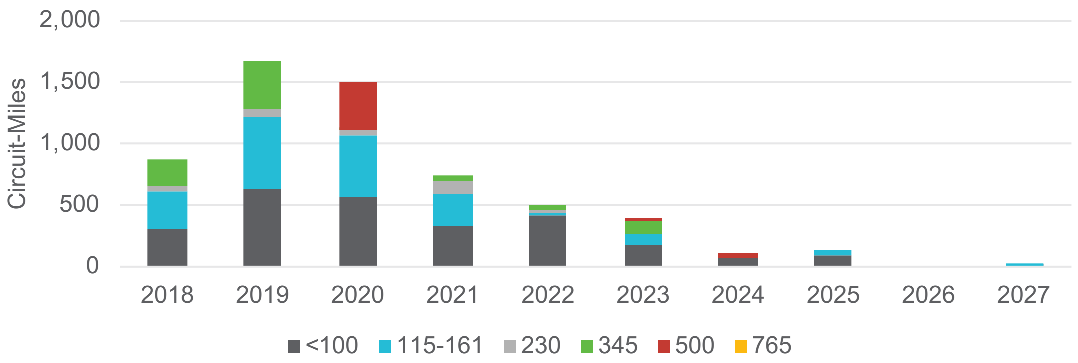
- In its latest transmission plan, MISO has identified $3.3 billion in transmission infrastructure investment. The top 10 projects represent 23% of that cost and are largely in the far north and south of the region (see upper right).
- Since its 2006 planning cycle, MISO has directed $10.7 billion in cost-shared projects; $6.5 billion were multi-value projects, which provide MISO region-wide public policy (e.g., renewables integration) and economic and/or reliability benefits (see lower right). MVPs were introduced to address large-scale emergence of wind resources.
- MISO has planned an addition of 5,900 circuit miles of new transmission, much of it (4,400 miles) at lower transmission levels (161 kV or less). Additions consist of 4,000 circuit miles of upgrades on existing corridors and 1,900 circuit miles of new lines on new corridors.
- Project spending in MISO's latest transmission plan is split roughly equally between new and upgraded lines and substation or switching station related construction and maintenance (including terminal equipment, circuit breaker additions and replacements, or new transformers).

MISO's Transmission Expansion Plan 10 Largest Projects (as of Dec. 2018)



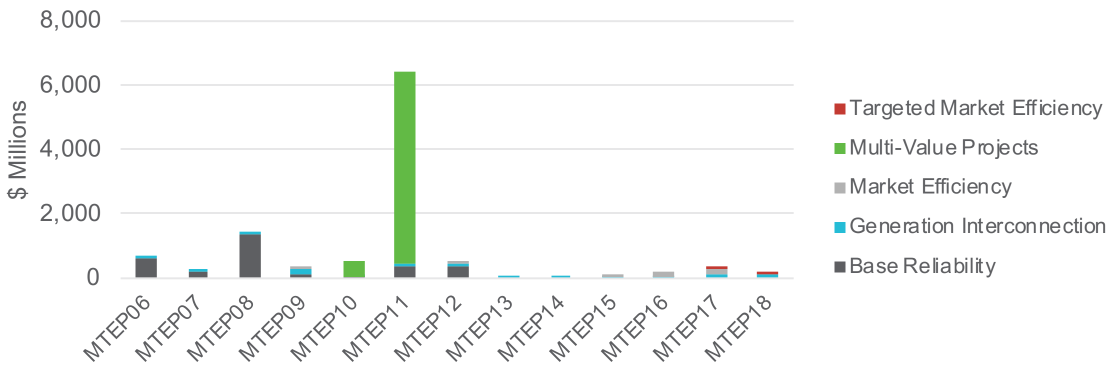
Source: MTEP18

MISO 2018 Transmission Plan Planned New or Upgraded Transmission Circuit-Miles by Voltage Class (kV) and Year



Source: MTEP18

MTEP06 to MTEP18 Cost Shared Project Costs by MTEP Cycle and Project Type (in $Millions)

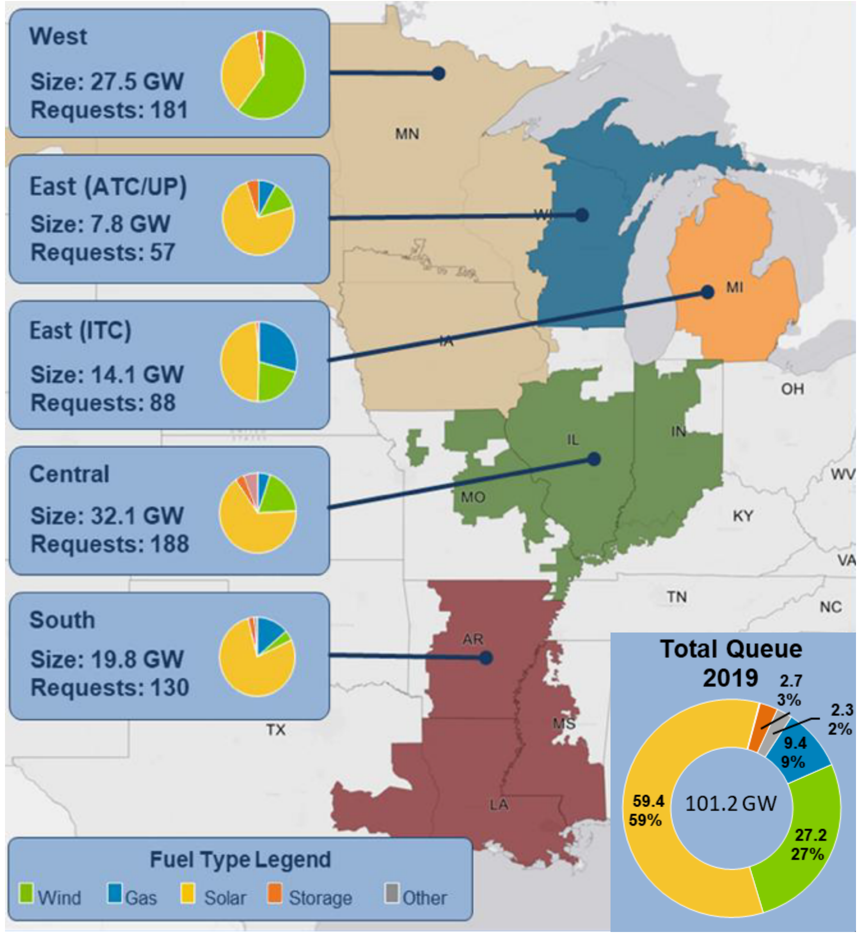


Source: MTEP18

Sources: MTEP18; MISO Resilience Testimony

Transmission Topography and Investment (Cont'd)

MISO Generator Interconnection Active Queue by Fuel Type and Region (as of June 2019)



Source: MISO

- MISO's latest analysis shows less congestion across its footprint than in prior planning cycles. It has invested in mitigating congestion, and the effects of competitive fuel prices and "stagnant" net demand growth have reduced congestion. However, it observes that the changing generation fleet (i.e., thermal generation retirements) and renewable additions may lead to congestion in specific areas.
- As of the release of its last transmission enhancement plan, MISO's generator interconnection queue consisted of 483 projects totaling 81.5 GWs (compare MISO's capacity of 175 GWs), a majority of which are solar and wind projects. The queue has grown to more than 101 GWs (with nearly 89 GWs of solar and wind) as of June 2019 (see chart at left). MISO is incorporating resource adequacy considerations in planning, as generation retires and is replaced by lower-capacity wind and solar resources.

MISO 2018 Transmission Enhancement Plan Appendix A Cost-Shared Projects

Category	Description	# of Projects	Total ($B)*	Largest Region Spend ($M)*
Baseline Reliability	Required for NERC, regional reliability	81	$0.7	South ($333)
Generator Interconnection Projects	Required to connect new generation to grid	16	$0.3	South ($149)
Other	Various, including lower voltage systems, local economic benefit, or don't meet market efficiency threshold	341	$2.3	West ($1,197)
Transmission Deliverability Service Projects	Network upgrades driven by transmission service requests	2	<$1M	South ($0.3)
Targeted Market Efficiency Projects	Interregional projects with PJM	2	$0.004	Central ($4.5)

*Rounded

Source: MTEP18

Source: MTEP18; June 2019 Resource Update

Resilience Issues

General Resilience Issues and Approach

- The area covered by MISO is broad with a diverse array of industries and weather. As a frame of reference for the potential economic impact of a resilience event, MISO's 2018 annual GDP for those states in its footprint (excluding Texas) was $3.8 trillion.*
- In MISO's comments to FERC in its grid resilience docket, it cites the following resilience risks in its region:
  - Because of its large geographic footprint, it can be susceptible to multiple events at one time. Key disruption types include communications interruptions; natural disasters, including potential effect on natural gas supply; and physical facility and cyber threats.
  - MISO considers its changing resource portfolio as having implications for resilience and related reliability efforts. Increased amounts of variable resources, both at the bulk (utility-scale) and sub-transmission and distribution level (distributed), together with reduced baseload resources require a fundamentally more flexible system. MISO has established a dispatchable intermittent resource capability product to provide operating flexibility and congestion management to accommodate large-scale wind.
  - MISO observes that most loss of load and interruption events occur at the distribution level, although transmission disruptions cover a broader area.
- MISO uses its transmission expansion-planning process to address resilience, with a view to provide diverse resources to effectively respond to events through real-time operations. Bulk system attributes evaluated through the transmission planning process include protection systems, reclosing schemes, redundant and backup protection schemes, and line ratings with sufficient margins. System analysis and visibility, such as data provided through synchrophasors and dynamic modelling, provide input to operations and planning efforts.
- MISO has multiple, active (staffed) control centers (MISO's headquarters in Indiana and two regional centers in Minnesota and Arkansas) and data centers that provide flexibility to operate in the event of a disruption.
- MISO believes that default use of transmission line relief (TLR) and curtailment of power transfers pursuant to TLRs are a less desirable approach to resilient operations, because they may block or curtail transfers across the Eastern Interconnection, even when redispatch options are available to reliably facilitate the original transaction. MISO believes that seams coordination and market-to-market transactions, together with redispatch, are more reliable and cost effective for relieving congestion.

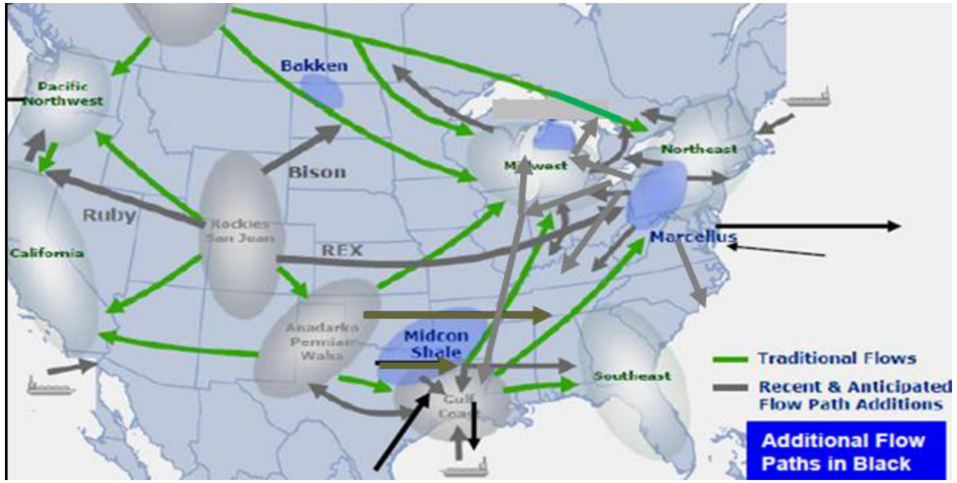
*Note: Figure applies to states of AR, IA, IL, IN, KY, LA, MI, MN, MO, MS, MT, ND, SD, WI; excludes TX.
Sources: MISO Resilience Testimony; Bureau of Economic Analysis; EIPC Study

Resilience Issues (Cont'd)

Gas Infrastructure Dependency Analyses

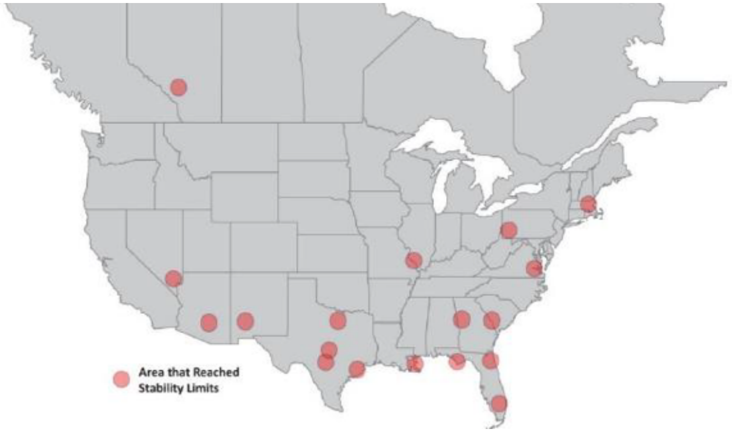
- With a large and growing set of natural gas-fired resources, MISO has been studying gas-electric coordination and potential effects of resilience events.
  - NERC conducted a special study of potential reliability impacts of disruption of natural gas delivery. It identified 24 geographic clusters with more than 2 GWs of gas-fired generation. Eighteen areas were found with a reliability risk, and two of those areas were in MISO's footprint—on the Missouri/Illinois border and around the Amite South load pocket in southeast Louisiana (see map at lower right). MISO has determined that those are not single source (N-1) issues, and the NERC analysis did not account for a generator's ability to procure fuel from an alternate pipeline.
  - In 2015, the Eastern Interconnection Planning Collaborative (EIPC) conducted a study of, among other things, adequacy of gas infrastructure to serve electric system demand. It found "affected generation" totaling 2.6 GWhs (5%) in eastern Wisconsin in high-winter peak-load conditions. However, "affected generation" does not imply a risk to electric reliability.
- MISO plans to address testing and verification of dual-fuel units in the future. However, EIPC has observed that there may be some limitations on backup fuel use because of air permit conditions, cost of conversion to dual fuel, and the EPA's new source rule implications.
- Since 2015, MISO has modeled gas infrastructure interruptions in its transmission planning. It now uses 31 gas contingencies, as extreme events, to evaluate system needs. It has found no cascading events, although in only one scenario—the extreme and long-term event of the loss of the largest natural gas pipeline for the entire summer-peak season—did planners observe a slightly elevated regional loss of load risk.
- In 2018, MISO investigated gas contingency risks, specifically historical (Jan. 2013 to Jan. 2018) pipeline and gas generator outages and found three things. First, the probability of any pipeline event occurring (regardless of size) is very small. Second, the impact of gas unit outage (due to fuel delivery disruption) to resource availability is mostly during winter months and within a narrow portion of the footprint, with a maximum of 915 MWs impacted in any operating hour. Third, the majority of gas generator outages are not related to a physical disruption.

Developing Gas Grid Flow Patterns and LNG Imports/Exports



Source: MISO Gas-Electric Planning Update

NERC-Identified Clusters Where Power Flow Issues Were Identified Upon Gas Delivery Disruption



Sources: MISO Gas-Electric Planning Update; NERC SPOD

Sources: EIPC Study; NERC SPOD; Gas-Electric Planning Update; Gas Study Results

Resilience Issues (Cont'd)

Recent Resilience Issue: The South Central United States Cold Weather Bulk Electric System Event of January 17, 2018

- **Summary:** On January 17, 2018, a large area of the south central region of the United States experienced unusually cold weather. Below average temperatures began to occur as early as Friday, January 12, from the Great Plains south through the Mississippi Valley. Going into the work week beginning Monday, January 15, MISO and other adjacent areas knew that Wednesday, January 17, was likely going to be the coldest day of an extremely cold week for much of their respective footprints. The below average temperatures in this area resulted in 183 individual-generating units within the footprints of MISO, TVA, and SERC experiencing either an outage, a de-rate, or a failure to start between January 15 and January 19.
- **Outages and De-Rates:** Between Monday, January 15, and the morning peak hour (between 7:00 a.m. and 8:00 a.m. CST) on Wednesday, January 17, approximately 14,000 MWs of generation experienced an outage, de-rate, or failure to start. Inadequate winterization was deemed a key factor.
    - Including generation already on planned or unplanned outages or de-rated before January 15, the four regions had more than 30,000 MWs of generation unavailable in the south central portion of their footprint by the January 17 morning peak hour.
    - Generator owners attributed at least 35% of the generation outages and de-rates on January 17 to the extreme weather condition—19% to freezing-related mechanical issues and 16% to cold-related fuel supply issues.
    - From January 15 to 19, natural gas-fired units were 70% of the unplanned generation outages and de-rates, when calculated by numbers of units, and 74%, when calculated by MW.
    - During the same period, gas supply issues caused by the extreme cold temperatures, including interruptible supply, low gas pressure, and other pipeline and gas supply issues, led to outages of 38 units, for a total of approximately 2,200 MWs.
- **Peak Winter Demand:** At the same time (January 17 morning), power demand in MISO south and MISO was above their respective winter "extreme" forecast peak, while adjacent TVA and Southern Company footprints were above their expected "50/50" winter peak.
- **MISO Energy Emergency**: Under normal conditions, this region is not capacity limited. However, with generator outages, MISO declared an energy emergency, because it had insufficient reserves to balance generation and load in the south portion of its footprint, while all four regions experienced system constraints. MISO was limited in its ability to move power southward within its region to 3,000 MWs, but it exceeded that limit (reaching a maximum of 4,331 MWs) subject to any potential reliability effects on adjacent regions. MISO experienced parallel flows that challenged operators.
- **Deliverability:** There was ample wind generation available in the northern portion of MISO. Deliverability of reserves was the principal issue.

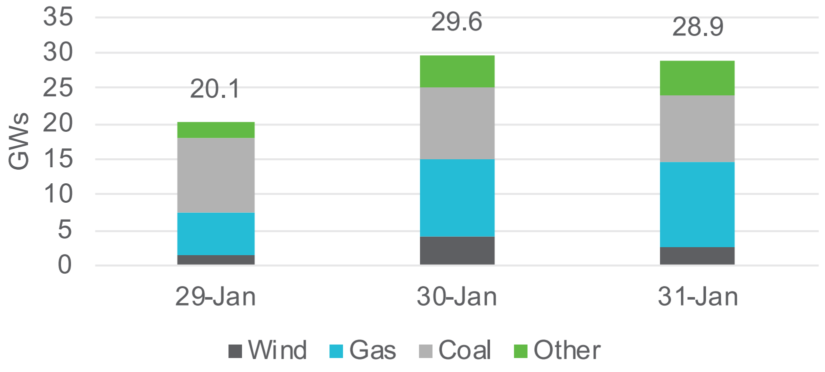
Source: Jan. 2018 Event Report

Resilience Issues (Cont'd)

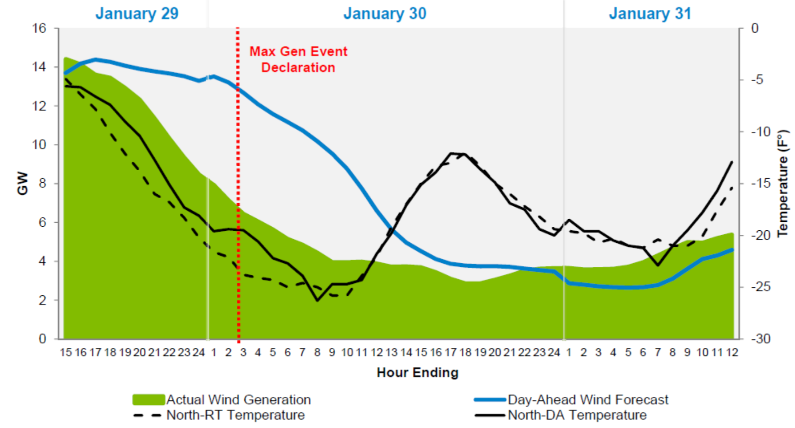
Recent Resilience Issue: Midcontinent ISO North and Central Region Maximum Generation Cold Weather Event (Jan. 30–31, 2019)

- **Summary:** On January 30-31, 2018, a strong Arctic high-pressure system brought historic cold to the North and Central Regions of MISO. North Region's low temperatures were 6°F colder than during the 2014 Polar Vortex event.
- **Outages, De-Rates, and Maximum Generation Declaration:** Cold-related mechanical issues and fuel supply limitations affected all generation types, with unplanned outages occurring across fuel technologies during the event (see chart top right).* Cold affected wind facilities as well (extreme cold can affect lubricants for wind gearboxes and bearings), causing an earlier than expected drop in wind output in the early morning of January 30 (see chart bottom right), increasing risk of resource insufficiency to meet the morning peak load and triggering a call of a Step 1 maximum generation event (call on emergency resources and to modify dispatch ranges). Subsequent conventional generation forced outages, uncertainty in the load forecast, and risk of additional outages caused additional emergency steps (Steps 2a-b: load management procedures).
- **System Response:** Voluntary load management, including school and business closings and deployment of load management resources, aided in reducing demand below expectations. Emergency pricing encouraged imports, including from south to north (compare January 2018 event on previous page). Imports into the North and Central Regions totaled in excess of 5 GWs during the January 30 evening peak and into the January 31 morning peak.
- **Results and Lessons Learned:** MISO successfully met planned and actual obligations, given the extreme temperatures, public safety concerns, forced outage risk, and import volume uncertainty. One lesson from the event was recognition of the need to incorporate additional generation resource-operating parameters, particularly temperature thresholds. Others included identified changes in load-forecasting variables as well as increasing visibility into performance and availability of load-modifying resources.

MISO North/Central Daly Average Unplanned Generation Outages* (GWs)



Forecast vs. Actual Wind Generation (GWs) and Temperature

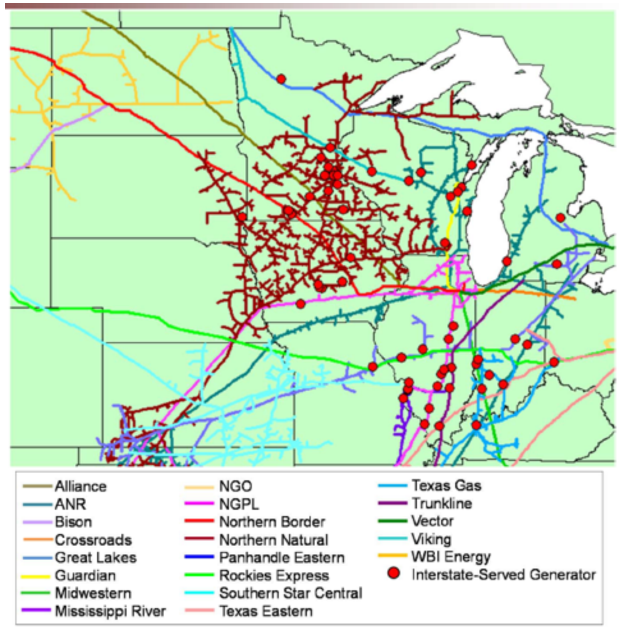


Note: *On January 30, 28% of wind capacity and 34% of gas capacity were in unplanned outages, or 25% overall during the entire event.
Source: Jan. 2019 Event Overview

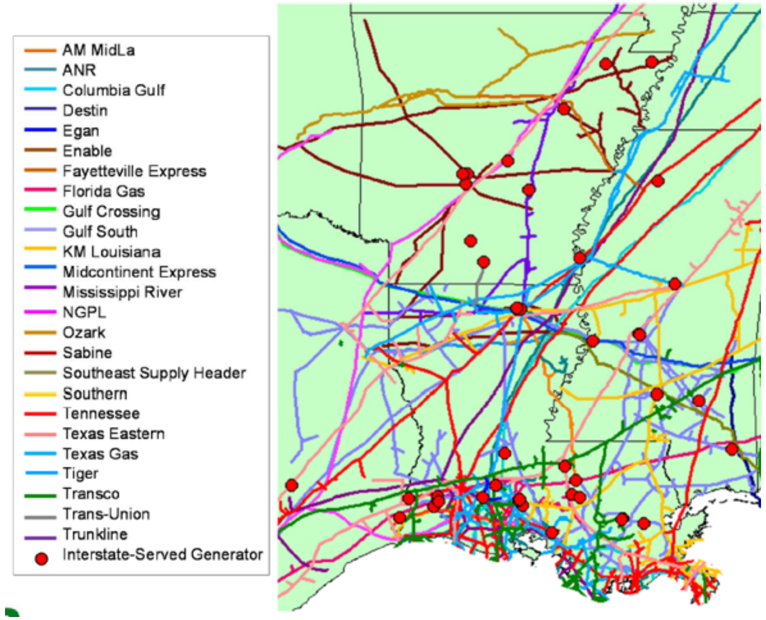
Resilience Issues (Cont'd)

- MISO's energy resource technologies vary, but it is mostly dependent upon wind, coal, and natural gas-fired generation. Gas-fired generation is particularly concentrated in the southern part of its footprint.
- There is abundant gas pipeline availability and access in the southern portion of the region, particularly in Texas and Louisiana. In the North/Central region, pipeline resources are characterized by a few large pipelines from the northwest and southwest feeding toward Chicago, with a larger network in the Minnesota/Wisconsin area.

Interstate Pipelines Serving MISO North/Central and Connected Generators (2015)



Interstate Pipelines Serving MISO South and Connected Generators (2015)

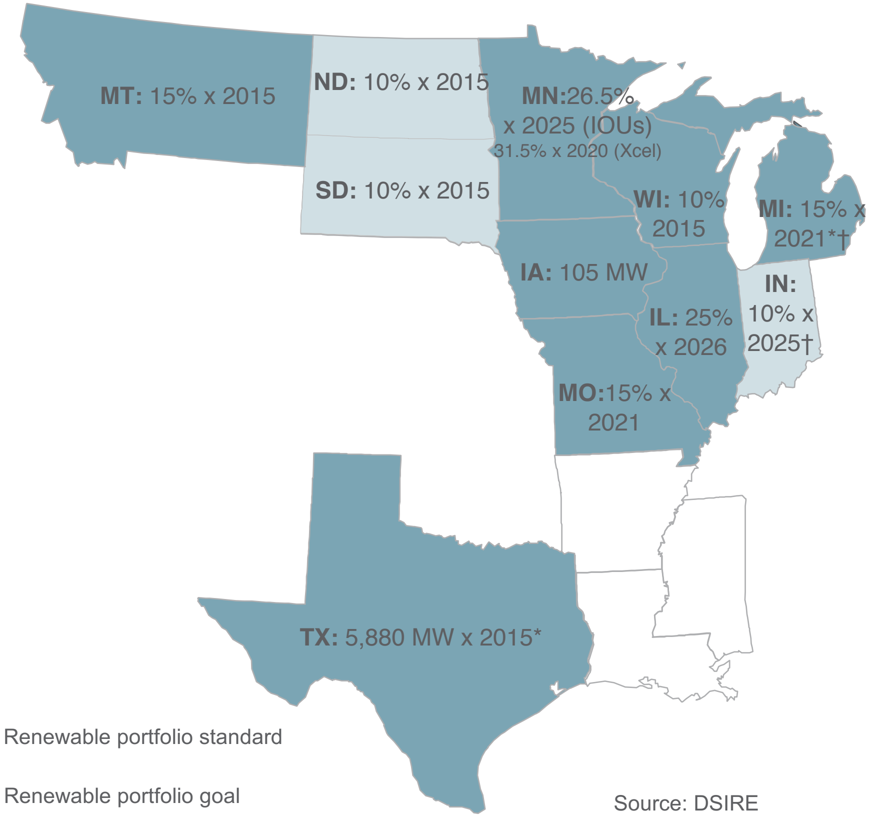


Source: EIPC Study

Sources: MISO Fact Sheet; EIA; EIPC Study

Renewables Integration

State Renewable Portfolio and Clean Energy Standards and Goals within the MISO Footprint (as of June 2019)



Renewable portfolio standard

Renewable portfolio goal

Source: DSIRE

* Extra credit for solar or customer-sited renewables

† Includes non-renewable alternative sources

Demand-Side Considerations

- Overall power consumption generally in the region was 683 TWhs in 2018, growing 4% from 657 TWhs in 2017. Longer term, MISO's demand and energy growth rates for planning purposes have declined over time. Its latest planning assumptions forecast a 0.29% compound annual growth rate in demand and 0.43% in energy through 2033.
- A number of states, both within and adjacent to MISO's footprint, have renewable and/or clean energy standards (see left). Minnesota has a relatively ambitious renewables standard, requiring investor-owned utilities to procure 26.5% of their power renewables by 2025. Illinois has targeted 25% renewables by 2026.
- Some utilities in states touched by MISO'S footprint have also introduced clean and renewable energy commitments (see next page).

Sources: MISO Fact Sheet; SEPA; DSIRE; NERC ES&D

Renewables Integration (Cont'd)

Utility Name (States of Operation)	Goal Type	Target Dates	Description (Date Implemented)
AEP Ohio	Emission Reduction	2050	80% emissions reduction below 2000 levels by 2050 (2018)
AES Corporation	Carbon Reduction	2030	70% carbon reduction through 2030 (revised its prior goal of 50% reduction from a 2016 baseline) (2018)
Alliant Energy	Emission Reduction/Renewable Energy	2050	40% below 2005 levels by 2030 and 80% of total emissions by 2050 (also eliminating all coal by 2050); 30% renewable energy by 2024 (2017)
Ameren	Emission Reduction	2050	80% emissions reduction by 2050 compared to 2005 levels (2017)
CMS Energy Corporation	Emission Reduction/Coal Elimination	2040	80% emissions reduction and no longer using coal by 2040 (2018)
DTE Energy	Emission Reduction	2040	80% emissions reduction by 2040 (2019)
Great River Energy	Renewable Energy	2030	50% by 2030 renewable energy (2018)
Madison Gas and Electric	Emission Reduction	2050	Net-zero carbon electricity by 2050
MidAmerican Energy (IA, IL, SD)	Renewables	N/A	100% renewables (2016)
NiSource, Inc./NIPSCO	Carbon/Coal Reduction	2030	90% carbon emissions reduction from 2005 levels by 2030 (2019); moving to coal free by 2028 (2018)
Otter Tail Corporation (MN, ND)	Renewable Energy	2031	30% renewables by 2031 (2017)
Vectren Corp	Emission Reduction	2023	60% emissions reduction by 2023 (2018)
WEC Energy Group	Emission Reduction	2030	40% emissions reduction below 2005 levels by 2030 (2018)
Xcel Energy (CO, MI, MN, NM, ND, SD, TX, WI)	Emission Reduction/ Carbon Reduction	2017 2030 2050	35% emissions reduction by 2017 (achieved) 80% below 2005 levels by 2030 Zero carbon by 2050 (2015)

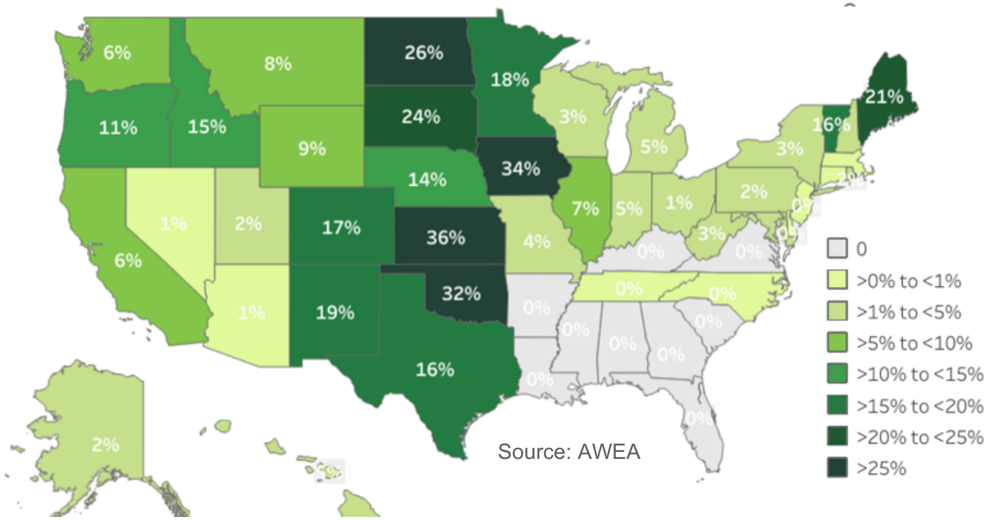
Source: SEPA (as of July 2019)

Renewables Integration (Cont'd)

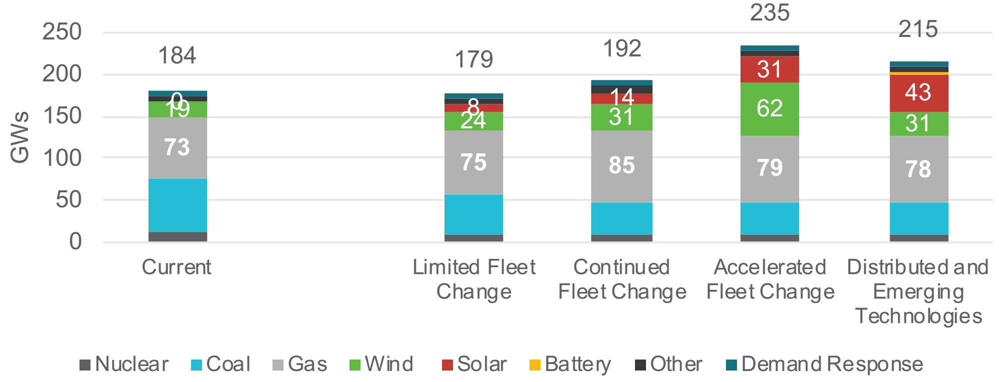
Supply-Side Considerations

- MISO has significant potential wind resources, although wind power constitutes only about 15% of installed capacity (10% of market capacity).
- In its most recent forward-looking scenarios for transmission planning, MISO has bounded 2033 installed wind capacity between 24 GWs and 62 GWs, up from an existing 19 GWs. This would comprise between 13% to 26% of 2033 market capacity. About 27%, or 27 GWs, of the generation interconnection queue at June 2019 was wind.
- Solar is emerging as a growing resource in MISO's footprint as well. For planning purposes, MISO's bounds expected installed capacity of utility-scale solar resources between 8 and 43 GWs, from a negligible amount today (314 MWs front-of-meter solar as of June 2019). In fact, 59% of the generation interconnection queue as of June 2019 (or 59.4 GWs) constituted solar (see lower right).
- Under its planning scenarios (see below), renewables penetration varies significantly. MISO assumes renewables penetration levels between 15% and 39% of capacity by 2033.

Wind Energy's Share of Electricity Generation by State (2018)

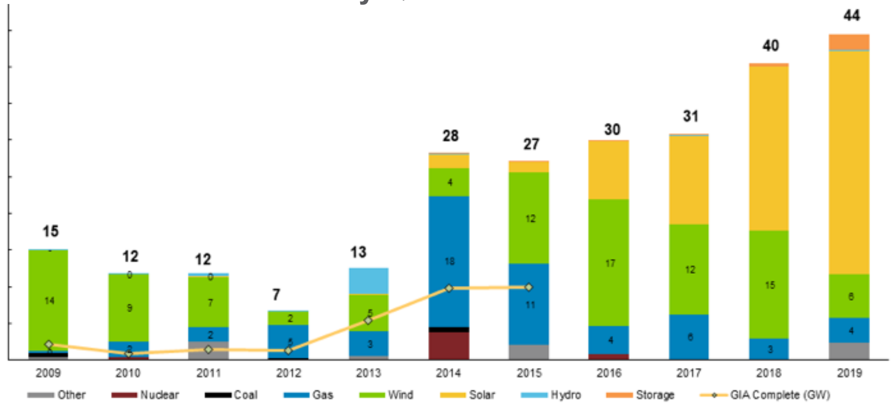


MTEP19 Futures Installed Capacity (GWs) by Type and Scenario (2018 vs. 2033)



Source: MISO

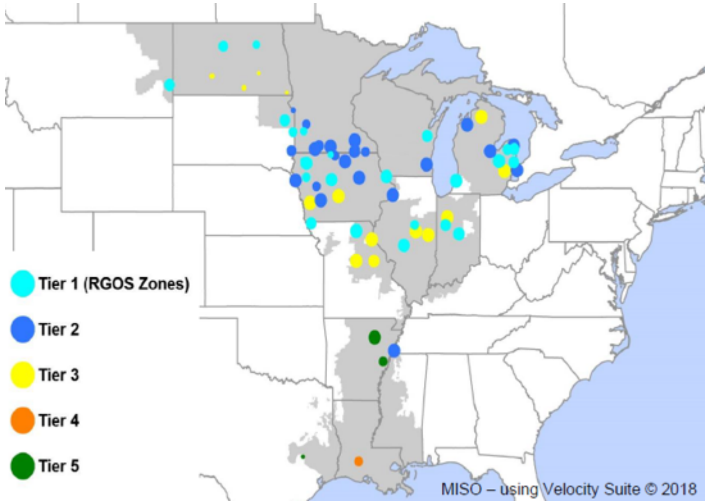
MISO Queue: Historical Trend of Requested Generation by Fuel Type (GWs) and by Queue Date Year



Source: MISO

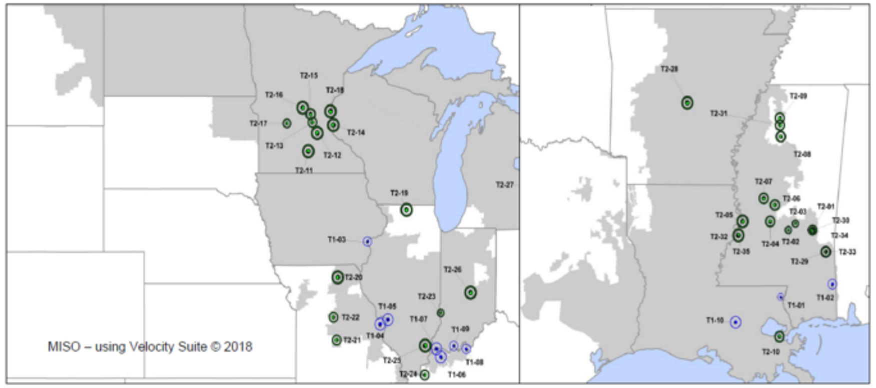
Renewables Integration (Cont'd)

Wind Regional Resource Forecast Unit Siting: 3.6 to 10.8 GWs Depending Upon Scenario



Source: MTEP19 Futures

Solar Regional Resource Forecast Unit Siting: 7.2 to 42.7 GWs* Depending Upon Scenario

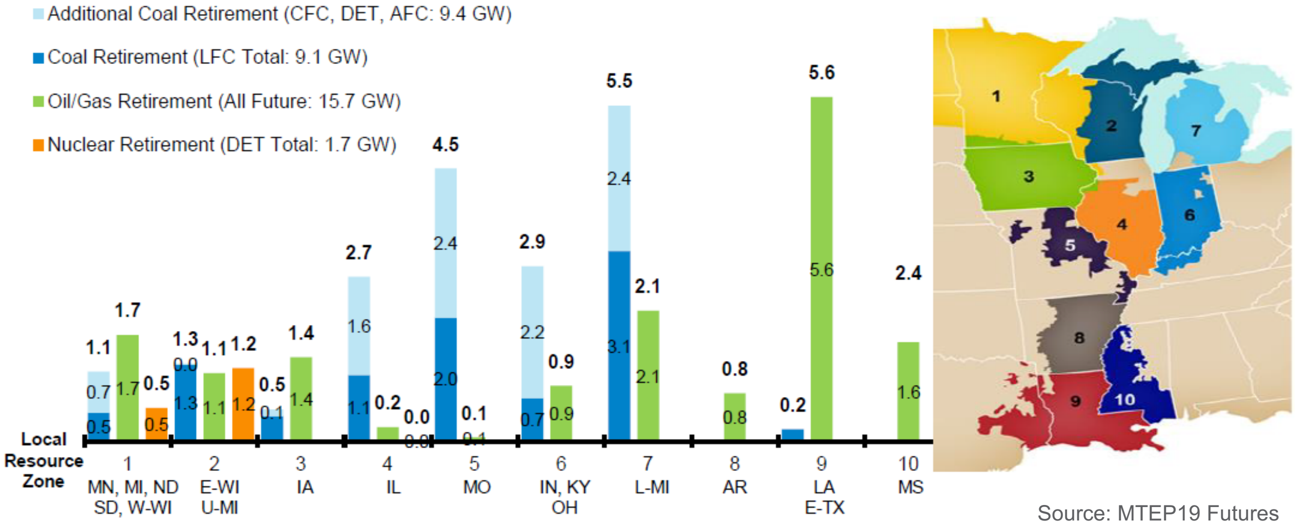


Source: MTEP19 Futures

Supply-Side Considerations – Retirements and Locational Considerations

- While renewables and some gas-fired generation dominate projected capacity additions, MISO expects significant retirements of coal, oil, and gas capacity. Its planning assumptions have thermal generation retirements of 25 GWs by 2033 in its most conservative case to more than 35 GWs in its more aggressive case of renewables development and carbon-reduction policies (see below).
- These assumed retirements are distributed through the footprint, but they are particularly prevalent in Illinois, Missouri, Indiana, Michigan, and Louisiana, while renewable additions are concentrated in the upper Midwest and Mississippi (see maps at left).

Assumed Thermal Generation Retirements by 2019 Planning Scenario and Local Resource Zone (GWs)

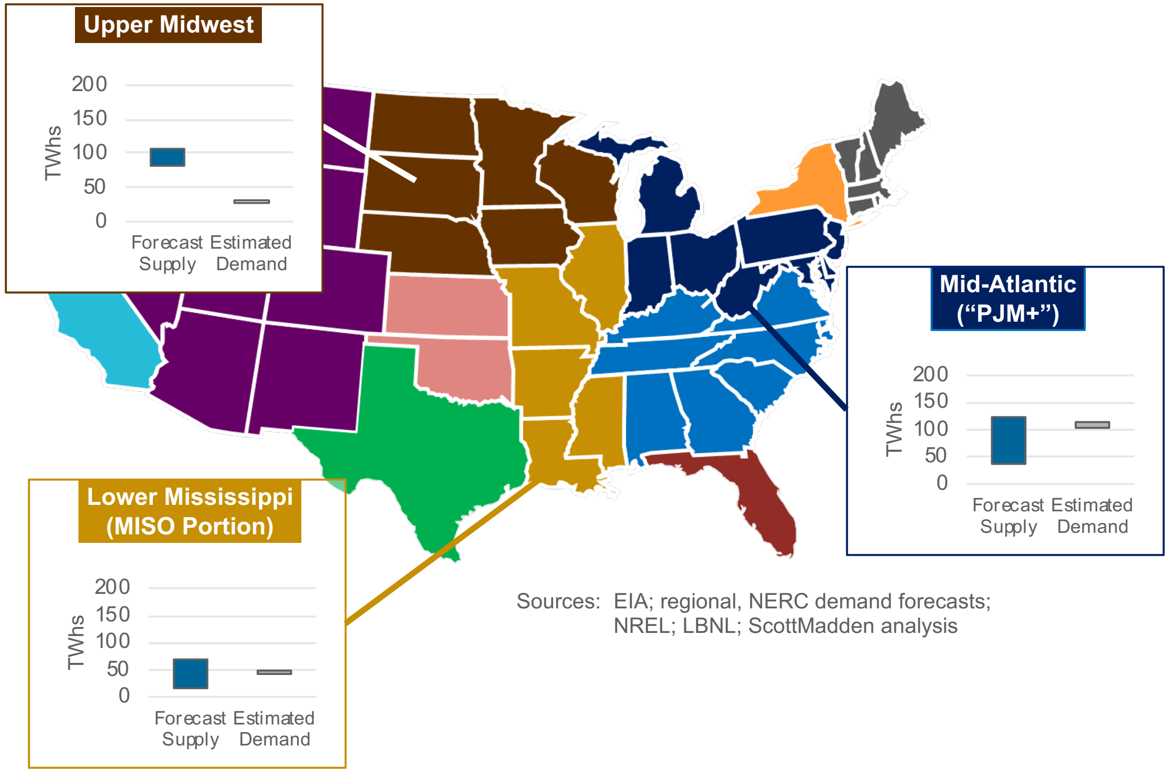


Source: MTEP19 Futures

Source: MTEP19 Futures
Notes: Tiers indicate priority and likelihood of completion. *Solar figures include 2.4 to 28.4 GWs of distributed solar resources.

Renewables Integration (Cont'd)

Midcontinent ISO-Area U.S. Potential Policy-Driven Renewable Energy Demand and Forecast Supply (2030) (as of June 2019)

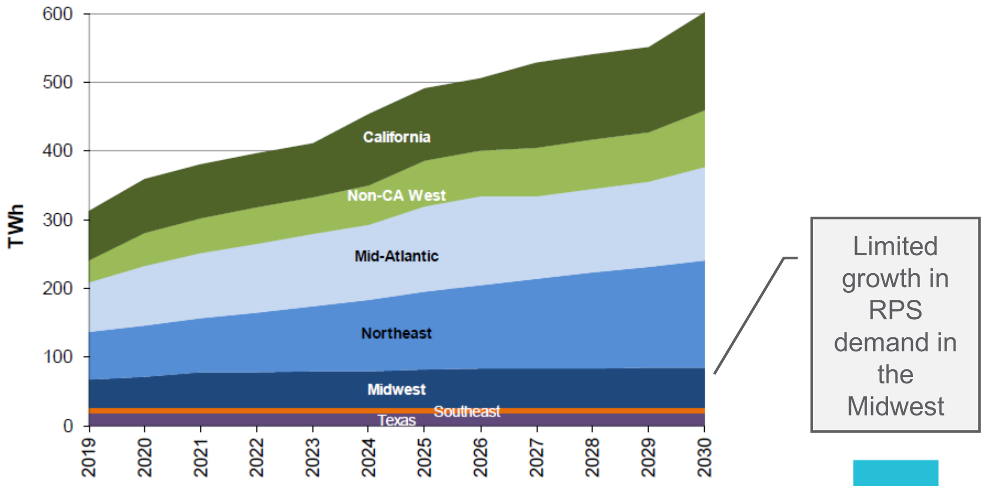


Sources: EIA; regional, NERC demand forecasts; NREL; LBNL; ScottMadden analysis

Integration Challenges – RPS Supply-Demand Balance

- Forecast renewables supply is greater than anticipated renewable portfolio standard (RPS) policy-driven growth in the Midwest, in particular the MISO market area. While there has been significant wind development, some has been contracted to utilities with RPS needs.
- A separate analysis by the American Wind Energy Association estimated that wind-eligible demand* in the Midwest (Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin) totals 3 GWs by 2030. As noted earlier, as of June 2019, more than 27 GWs of wind resources were in the generation interconnection queue in MISO.
- Lawrence Berkeley National Laboratory (LBNL) notes that RPS capacity additions (10% or 9 GWs) extend to 13 states without an RPS, with the most significant including MISO states Indiana and North Dakota as well as Wyoming. Two others with no further RPS obligations—Kansas and MISO state Iowa—host significant RPS capacity for others.
- This RPS supply-demand imbalance illustrates the role of interstate transmission capacity for interstate commerce for RPS compliance.

Projected U.S. RPS Demand (Total Compliance Requirements) per DOE LBNL (2019–2030) (as of July 2019) (in TWh)



Notes: *Per AWEA, wind eligible demand is the amount of renewable energy needed to meet RPS requirements for which wind is an eligible technology. This excludes technology carve-outs, separate resource classes, and energy efficiency requirements. This category represents the remaining RPS procurement needs that wind is eligible to capture and the maximum RPS market opportunity for wind.

Sources: LBNL 2019 RPS Analysis; AWEA 2019 RPS Analysis; EIA; regional, NERC demand forecasts; NREL Standard Scenarios; LBNL; ScottMadden analysis

Renewables Integration (Cont'd)

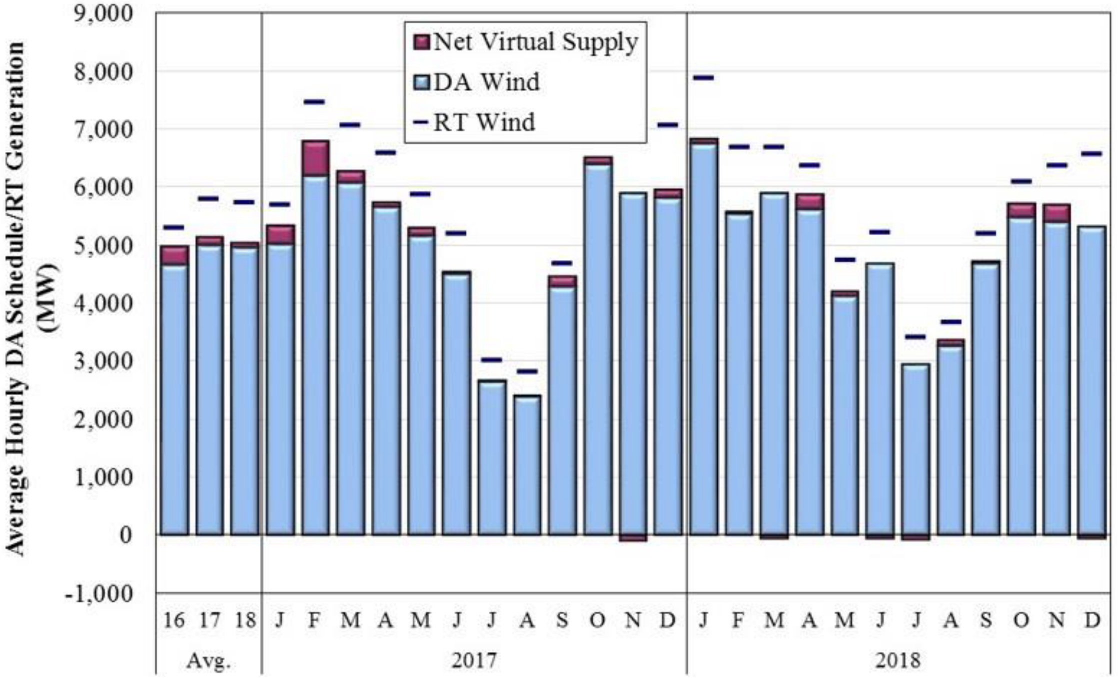
Integration Challenges (Cont'd) – Other Integration Issues

- Wind and solar integration bring low-cost generation to the MISO region, but accredited capacity associated with those technologies is lower than their nameplate capacity because of probabilistic estimates and historical performance of those resources. The effective load-carrying capacity (ELCC) is the amount of incremental load a resource can dependably and reliably serve and is based upon. This capacity value (as % of nameplate) is used to determine resource adequacy in a local resource zone for reliability, particularly to plan to less than one day in 10 years for expected loss of load (unserved load). ELCC does not necessarily indicate energy output over time or at a particular time.
  - MISO performs an annual analysis of installed wind and solar capacity to determine ELCC and in particular MISO's capacity credit. MISO analyzed 215 nodes where 2,855 MWs of wind generation were present. For the 2019–2020 planning year, MISO-wide wind capacity credit is 15.7%, an increase of 0.5% from MISO's 2018 capacity credit. Wind output is lower during summer months than during shoulder months, which reduces its reliability value.
  - Because of the small amount of solar resources on its system and pending sufficient-operating history of summer performance, MISO applies a 50% class average credit to solar resources. In its long-term planning, and assuming higher penetration of solar and wind resources on its system, MISO projects that the solar capacity credit will fall to 30% by 2033.
  - Per its 2018 transmission plan, MISO assumes less capacity availability because of the on-peak performance of generators (including renewable resources), transmission limitations, and energy-only capacity; MISO assumes on-peak capacity of 148.6 GWs, significantly less than its current nameplate capacity (170.5 GWs).
  - Diversity of resources—technology diversity (i.e., solar and wind evaluated together) and geographic diversity—improves overall renewable ELCC.
- Wind generation accounted for 8% of generation in 2018. Installed capacity exceeded 19 GWs, with 1.9 GWs entering the market in 2018 with more expected. Because of its variability, wind presents operational challenges, particularly as its share of total output increases. It should be noted that real-time wind generation averaged 5.7 GWs per hour (about 30% of total wind capacity), and its all-time record was on March 15, 2019, at 16.3 GWs (about 86% of total wind capacity).
  - One issue MISO faces is under-scheduling wind. Wind suppliers often under-schedule their output in the day-ahead market than their real-time output (see next page). This is in part because of some supply contract terms and wind producers' management of financial risk of under-delivery. Under-scheduling of wind averaged 770 MWs per hour in 2018 and exceeded 1,000 MWs (more than 5% of wind capacity) in three months. This creates price volatility (as other resources must be procured to cover potential shortfalls) and congestion that must be alleviated.
  - Another issue is the opposite concern—over-forecasting wind output in real time. Since wind resources are low or no marginal cost, they are scheduled for dispatch first; under-delivery due to forecast error results in dispatch deviations. MISO's market monitor has observed that the over-forecasting rate is higher in summer months, even as wind output is lower during those months (see next page).

Sources: MTEP18; ELCC Study; MISO 2018 SOM; Apr. 2018 RIIA Update

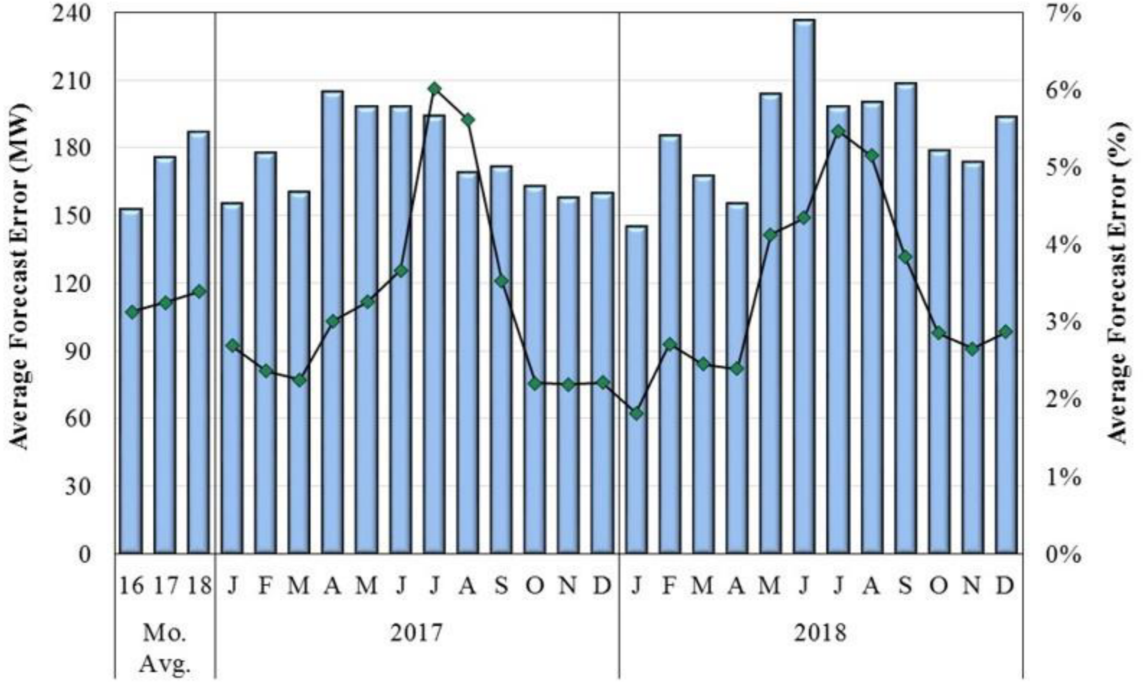
Renewables Integration (Cont'd)

Day-Ahead and Real-Time Wind Generation and Net Virtual Supply (2017–18)



Source: MISO 2018 SOM, Fig. 24

Generation Wind Over-Forecasting Levels (2017–18)



Source: MISO 2018 SOM, Fig. 25

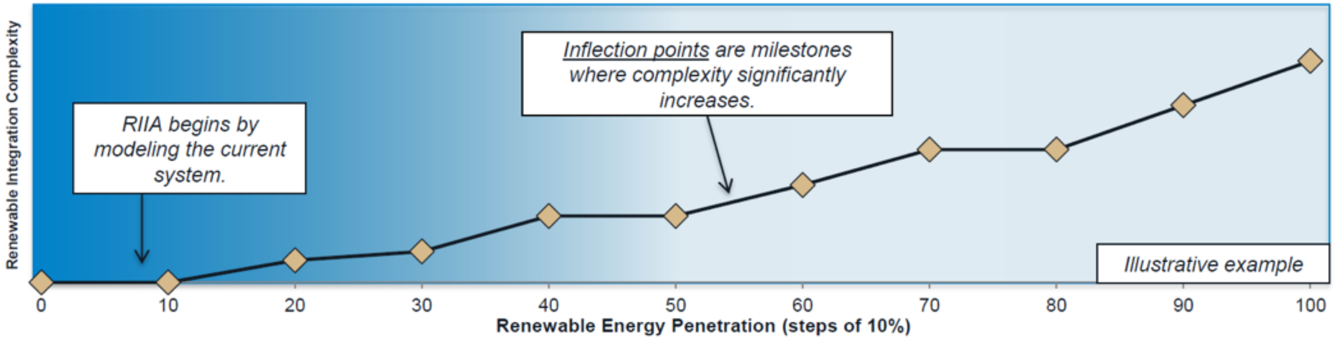
- MISO is working on market fixes to aid wind integration, including a ramp product, shortage pricing, and incentives for improved wind forecasts.

Renewables Integration (Cont'd)

Integration Challenges – Renewable Integration Impact Assessment (RIIA)

- Renewable resources, specifically wind and solar resources, have been the fastest-growing class of resources in MISO. MISO has observed that many of its legacy power plants that generated the bulk of its electricity have or will retire and be replaced by natural gas-fired and renewable resources. It has also observed the increased interest in energy efficiency, demand-side programs, energy storage, and distributed energy systems (like rooftop solar).
- In 2017, MISO launched an effort to develop a framework that considers grid impacts, including transmission and system performance. The purpose of the RIIA study is to find system inflection points—levels of renewable penetration as they affect complexity, including system stability, resource adequacy, and operational control (see graphic below).
- In the RIIA, MISO has been looking at inflection points driven by 10% increments of increased renewable energy penetration at which underlying infrastructure and/or system operations must be changed to accommodate that next level of renewables. The analysis is split into modules, which consider various system adequacy issues (see table at right). It also considers a range of potential solutions to mitigate impacts identified (see table at right).

RIIA Conceptual Approach: Finding Inflection Points of Renewable Integration Complexity



Source: Nov. 2018 RIIA Update

RIIA Impact Identification Metrics

Operational Adequacy	Steady-State Adequacy	Stability Adequacy	Resource Adequacy
• System ramp • Over/under generation • Transmission congestion • Operating and ramping reserves	• Voltage support • Frequency support • Short-circuit length	• Voltage stability • Frequency stability • Transient stability	• Loss of load expectation • Renewable capacity credit

Source: RIIA Concept Paper

RIIA Impact Mitigation Potential Solutions

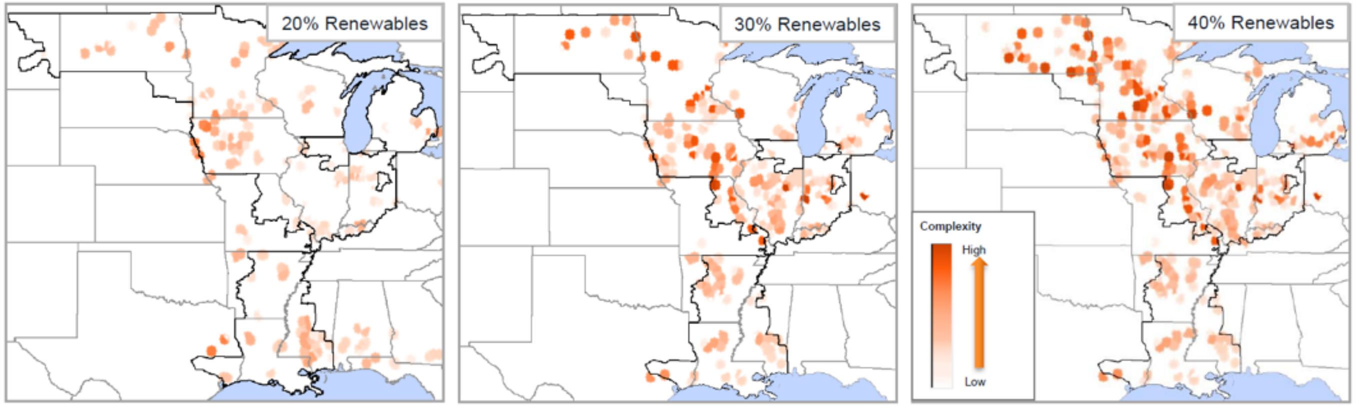
Transmission	Resources	Operations
• Lines • Buses • FACTS • Synchronous condensers • Energy storage	• Demand response • Fast-ramping generation • Require units to provide frequency response, inertia, and/or dispatchability • Energy storage	• Increased coordination • Increased operating reserves • Maintenance of frequency performance

Source: RIIA Concept Paper

Sources: RIIA Concept Paper; Apr. 2018 RIIA Update; Nov. 2018 RIIA Update

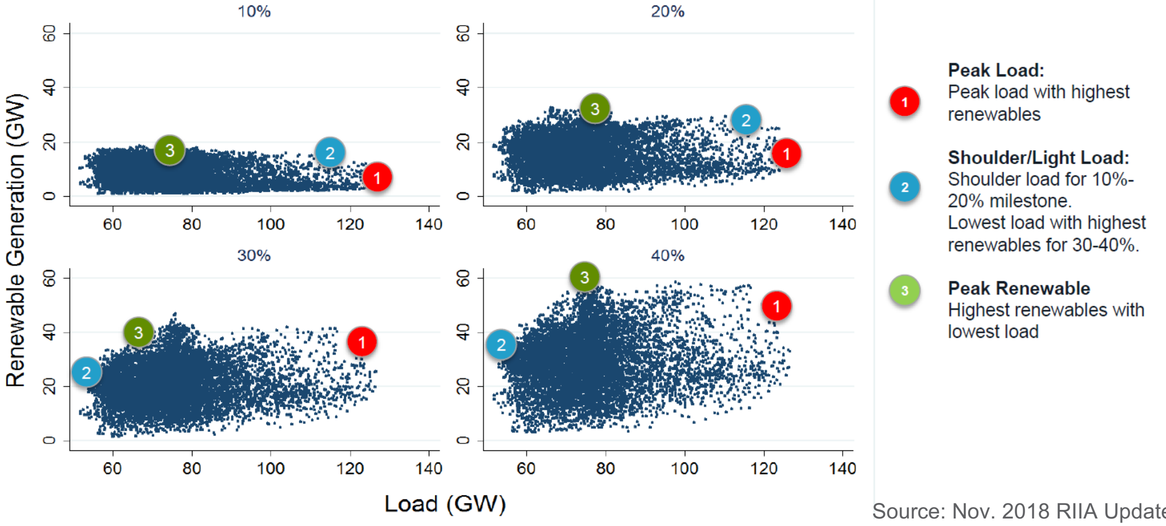
Renewables Integration (Cont'd)

Change in Steady State Solution Complexity With Increase in Penetration Level



Source: Nov. 2018 RIIA Update

Points of Transmission Stress Change as Renewables Penetration Grows



Source: Nov. 2018 RIIA Update

Integration Challenges – RIIA (Cont'd)

- As of late 2018, MISO's early findings in its RIIA analysis were as follows:
  - Integration complexity increases sharply from 30% to 40%, with that inflection point driven by energy adequacy.
  - Beginning at about 20% penetration, integration challenges (particularly renewable curtailment of anywhere from 6% to 18%) grow.
  - Curtailment, particularly of wind, is used to accommodate maximum variability swings (ramping). In the 40% penetration RIIA case, only 32% of MISO's load is served by renewable energy. At 40%, transmission expansion is needed to use the diverse variable resources across MISO's footprint.
  - Integration complexity (see maps at left) is measured as the approximate cost of the transmission fixes needed for steady state reliability issues, with the majority of the integration cost from fixes for transmission thermal violations. At 20%, complexity is relatively mild, but it increases with increasing penetration.
  - As renewable penetration increases, the risk of losing load compresses into a small number of hours and shifts to later in the day, from mid-afternoon to around 6:00 pm. However, the available energy from wind and solar during high-risk hours decreases. A thermal unit's average hourly generation decreases with increased penetration, but ramping volumes (as % of maximum capacity) increase.
  - Transmission stress changes (see lower left) with higher penetration—no longer concentrated on high-load periods, but also causing stress during shoulder/light load periods.

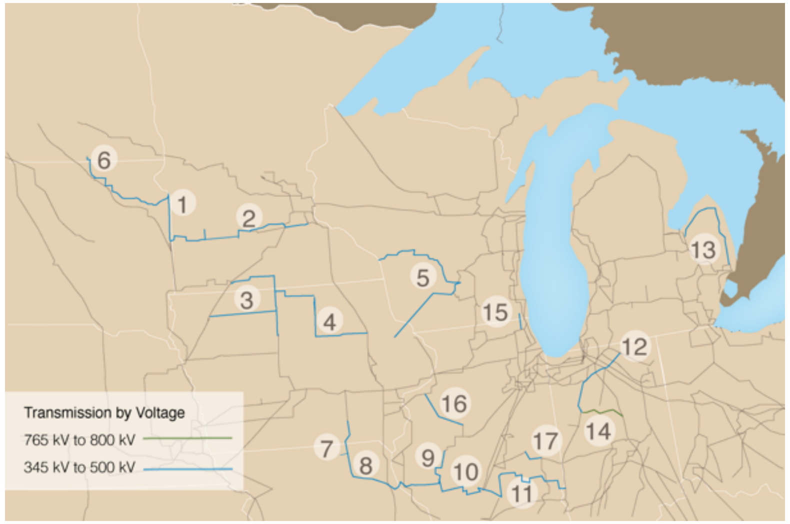
Sources: Apr. 2018 RIIA Update; Nov. 2018 RIIA Update; IAEE

Renewables Integration (Cont'd)

Integration Challenges – Multi-Value Projects (MVPs)

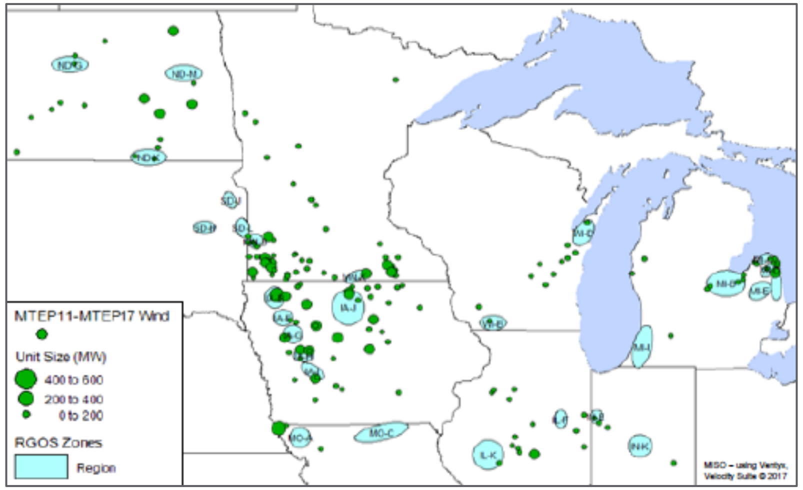
- MISO introduced MVPs in its 2011 transmission planning process to address increasing renewable resources, policy mandates (e.g., renewable energy mandates), and economic enhancements in its footprint. These regional transmission solutions are designed to meet one or more of three goals:
  - Reliably and economically enable regional public policy needs
  - Provide multiple types of regional economic value
  - Provide a combination of regional reliability and economic value
- The MVP portfolio is reviewed annually in MISO's transmission planning cycle, with more comprehensive reviews triennially. Those reviews include cost-benefit analysis, as projects are completed; system benefits, such as congestion relief; and fuel savings.
  - The 2018 annual review found the improved cost-benefit ratio of MVPs over their initial estimates, ranging from 2.0 to 3.1. The largest economics benefits consisted of congestion and fuel savings (about $16 billion to $56 billion) to MISO's North and Central regions and regional wind turbine investment ($1.2 billion to $1.4 billion).
  - According to MISO, 11.3 GWs of dispatched wind generation would be curtailed without the MVP portfolio. The MVP portfolio enables nearly 53 million MWhs of renewable energy to meet renewable mandates and goals through 2031. It also enables more than 5.1 GWs of incremental installed wind capacity over that same period, much of that in Michigan, Wisconsin, and Indiana. Much of the wind enabled is in the North and Central regions.
  - MVPs provide qualitative benefits, such as decreasing natural gas risk (fuel diversity), increasing geographical distance between wind generators (allowing for resource diversity), and enabling deliverability of all types of generation.

MISO Multi-Value Project Portfolio



Source: 2017 Triennial Review

MISO North/Central Wind Projects (2012–Apr. 2017) and RGOS* Zones



Source: 2017 Triennial Review

Sources: 2017 Triennial Review; MTEP18
Note: MVP benefits are estimated based upon a 20- to 40-year present value.
*RGOS means Regional Generation Outlet Study, a precursor to MVPs, that identified a set of value-based transmission projects necessary to enable load-serving entities to meet their RPS mandates.

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Implications for Transmission

	Resilience	Integration of Renewables	Other Factors	Transmission Opportunities
Midcontinent ISO	▪ Resource portfolio "transformation" to gas, intermittent resources—net gas capacity additions of 57 GWs from 2017–2021 ▪ Seasonal weather risks: extreme cold, heatwaves, flooding ▪ Geographic diversity (broad north-south footprint) affords weather diversity as well as multi-threat exposure ▪ Some gas infrastructure interruption exposure with major event, esp. in MO/IL border and south	▪ Interconnection queue of 101.2 GWs as of June 2019: 59.2 GWs solar, 27.2 GWs wind ▪ Wind capacity credit only about 15% of nameplate ▪ Renewables accounted for 9% of energy in 2017 and growing ▪ Increasing complexity with higher-renewable penetration: ramping needs, shifting net peak load later (from 3 PM to 6 PM) over smaller number of hours ▪ High curtailment (~60% of 2031 wind energy) without MVP projects ▪ Regional differences, with targeted integration issues in MISO West, which has much greater renewables penetration levels	▪ Scenario planning (10–15 years) examines various levels of penetration, with an energy mix from 13% to 36% wind and solar and up to 32% gas ▪ Tariff approach: dispatchable intermittent resource product aids incremental wind in real-time due to better forecasting ▪ Expected retirements of ~16 GWs largely thermal; while resource adequacy sufficient, increasing emergency events ▪ Public policy differences between north and south of region	▪ Increased north/south transfer limits to support resource diversity, resilience needs during gas events in south ▪ Increased internal capacity to co-optimize resources, reduce curtailment, and limit price volatility ▪ Pursuing coordinated system plan with PJM to reduce congestion on market-to-market flow gates ▪ Per latest MTEP, $3.3B in transmission planned in 2018; about 2/3 of lines are upgrades on existing corridors, 1/3 to be new lines ▪ Investment of nearly $6.5B in cost-shared multi-value projects from 2006 to 2017, but reflects 2011 circumstances (policy, anticipated renewables build, etc.)—opportunity for updated study ▪ Possible upgrades in anticipation of "tipping point" of 30%–40% renewables penetration in some MISO zones

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- U.S. Dept. of Commerce, Bureau of Ecommerce Analysis
- Regional, state, NERC demand growth forecasts
- S&P Global Market Intelligence