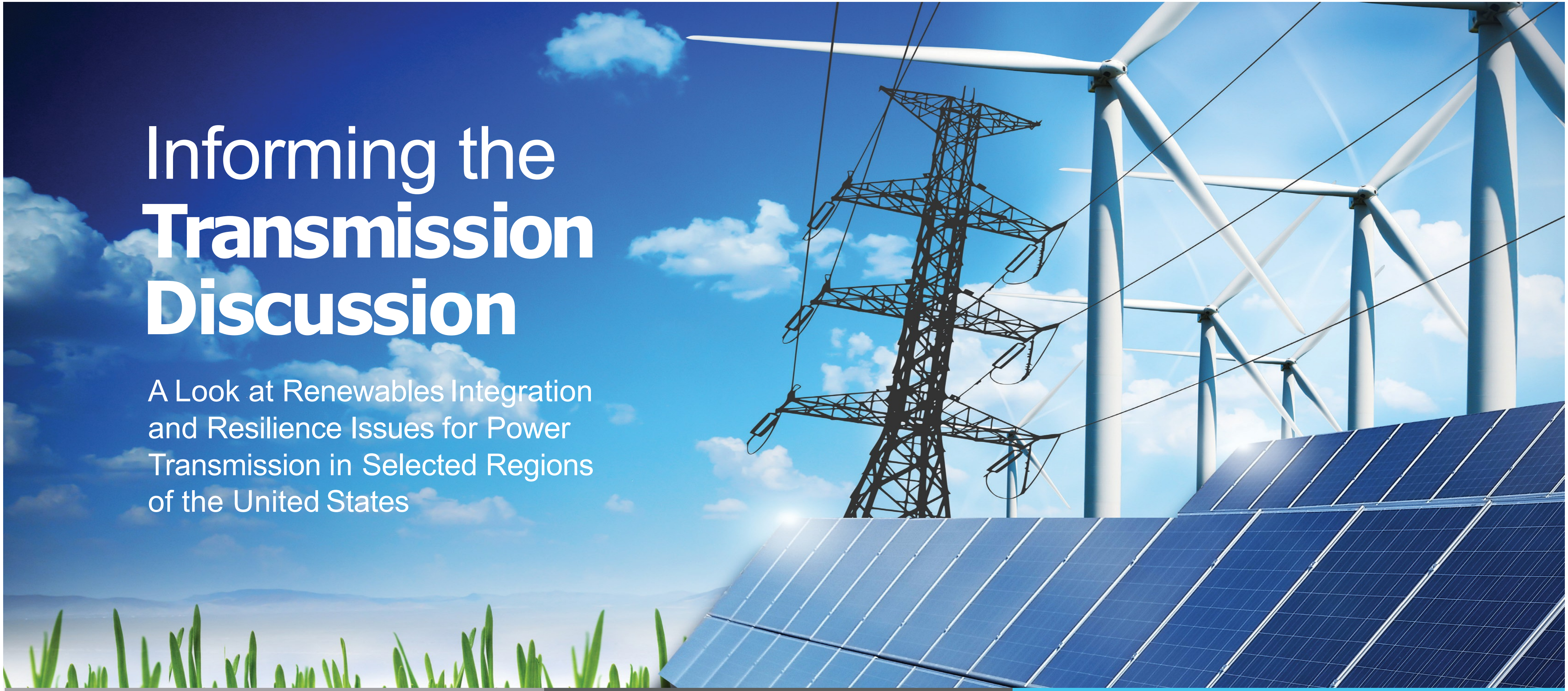


Informing the **Transmission Discussion**

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

PJM INTERCONNECTION

Contents

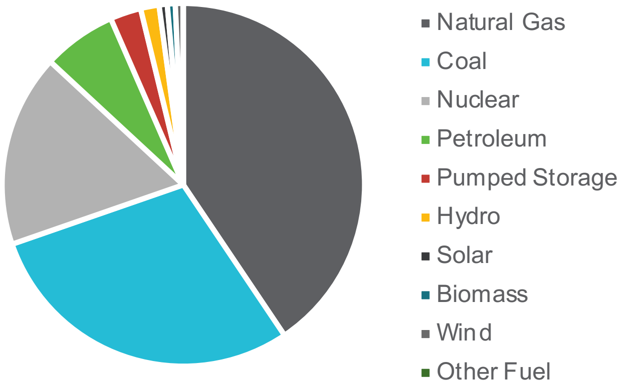
Overview

Description of Region

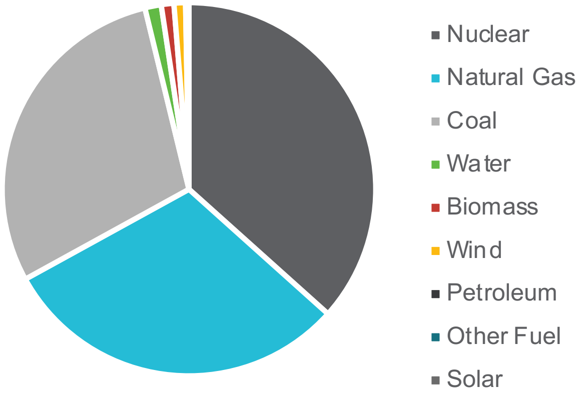
- PJM Interconnection is a regional transmission organization that coordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and the District of Columbia.
- Anticipated reserve margins will remain above the reference margin level (installed reserve margin requirement) throughout the assessment period (through 2028).
- PJM serves as balancing authority, planning coordinator, transmission planner, resource planner, interchange authority, transmission operator, transmission service provider, and reliability coordinator for its members.

Key Regional Statistics	
States Covered	DC, DE, IL, IN, KY, MD, MI, NJ, NC, OH, PA, TN, VA, and WV
Square Miles Covered	369,089
No. of Utilities	Members include 1,018 different entities
No. of Customers/Pop. Served	65M customers
Installed Capacity	54,586 MWs
Transmission Line Miles	84,200
Peak Hour Demand (2018)†	145,637 MWs summer (137,465 MWs winter)
Net Energy for Load	773,646 GWhs
Forecast Growth (Annual)	-0.34%-0.66% peak load growth -0.04%-0.90% demand (usage) growth

2018 Capacity Mix by Fuel



2018 Energy Mix by Fuel



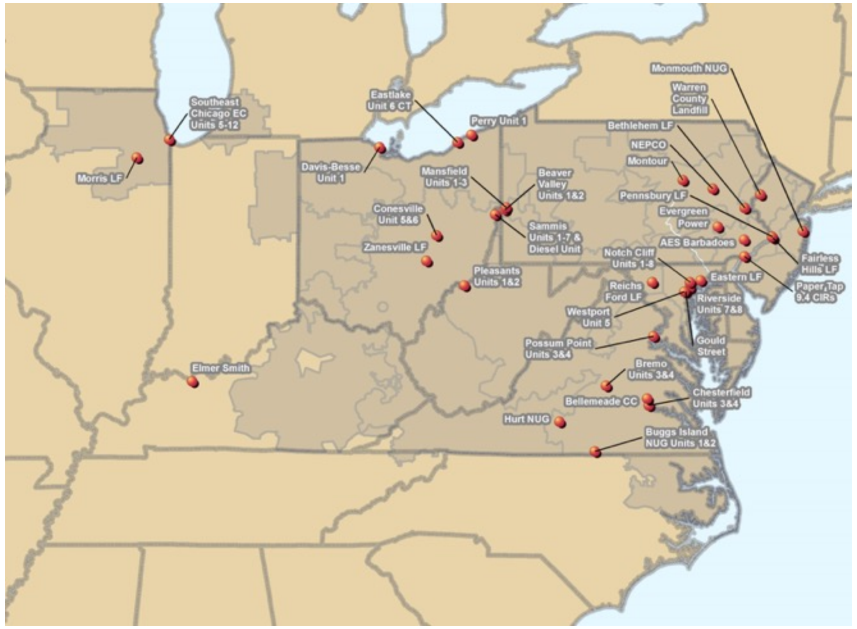
Sources: NERC 2018 LTRA, NERC ES&D; S&P Global Market Intelligence
† Note: Not necessarily coincident; constitutes a sum of assessment area peak-hour demand.

Overview (Cont'd)

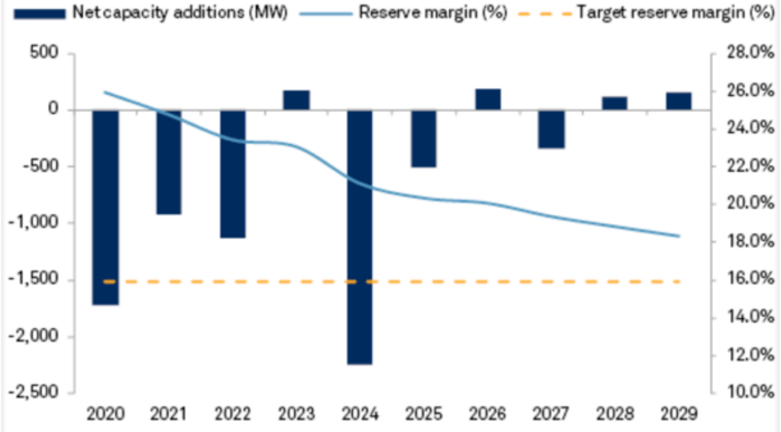
Generation Fleet in PJM

- **Adequate Resources for Now**: PJM has more capacity than it needs to meet planning reserve margins. Until 2019, expansion of gas-fired generation has outpaced the retirement of coal and nuclear generation, pushing reserve margins higher. With the pipeline of firm, new gas generation projects declining, reserve margins are expected to decline over the next 10 years as retirements outpace additions. Still, reserves are likely to remain above targets, especially now that Ohio has moved to subsidize the Perry and Davis-Besse nuclear plants and prevent them from deactivation.
- **Retirements**: From 2011 through 2018, 31,722 MWs of generation has retired, including more than 24,000 MWs from 125 coal-fired units, some more than 45 years old.
  - Coal: If formally submitted deactivation plans materialize, more than 25,000 MWs of coal-fired generation will have deactivated between 2011 and 2020. The economic impacts of environmental public policy coupled with the age of these plants make ongoing operation prohibitively expensive.
- **Replacements Mostly with Gas Generation**: Retiring units have been replaced by more than 38,000 MWs of new resources, including more than 29,500 MWs of additional Marcellus and Utica shale natural gas-fired generation and 5,910 MWs of renewable wind and solar generation.
  - Natural gas-fired generation capacity now exceeds coal in PJM. Natural gas plants total more than 65,600 MWs and comprise 86% of the generation currently seeking capacity interconnection rights in PJM's new generation queue.
  - The expansion of natural gas production within the PJM footprint has led to a surge in natural gas generation's share, from 12% in 2010 to 28% by 2017. Despite little new-added generation after 2019, favorable price trends are projected to push gas generation's share in the PJM market to nearly 45% in 2022–2023. Part of this growth is attributable to announced retirement of nuclear plants in the region.

PJM Generator Deactivation Requests
(January 1 through December 31, 2018)



PJM New Capacity and Reserve Margin Forecast (2020-2029)



Data as of March 31, 2019.
Source: S&P Global Market Intelligence

Sources: NERC 2018 LTRA; Benefits White Paper; S&P Global Market Intelligence

Transmission Topography and Investment

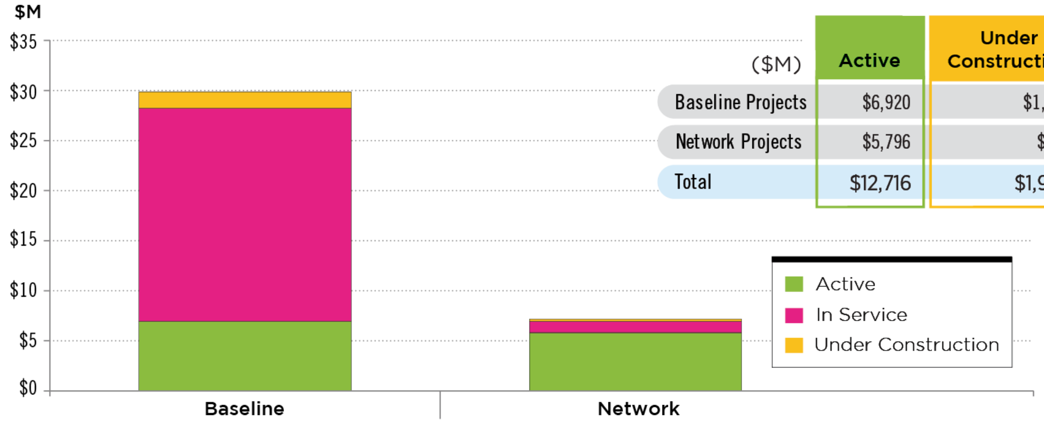
PJM Board-Approved Transmission Expenditures

- **Historical Investment**: Since 1999, PJM's board has approved transmission system enhancements totaling $37.1 billion. Of this, $29.9 billion represent baseline projects to ensure compliance with NERC, regional and local transmission owner planning criteria, and address market efficiency congestion relief. An additional $7.2 billion represent network facilities to enable more than 85,000 MWs of new generation to interconnect reliably.
- **2018 Additions**: The numbers depicted at right provide a snapshot of one point in time, as with an end-of-year balance sheet. The $37.1 billion total reflects a net $2 billion increase over December 31, 2017.

Shifting Regional Transmission Expansion Plans (RTEP) Dynamics

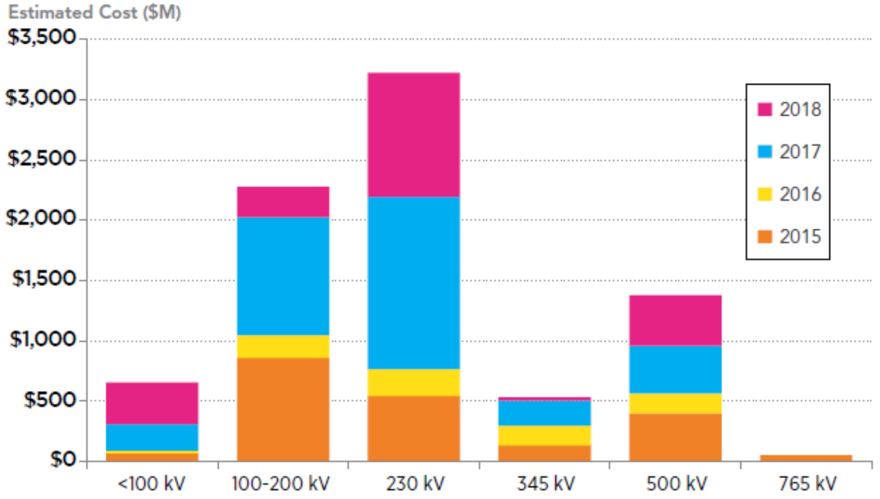
- **Shift in Drivers**: Flat-load growth, energy efficiency, generation shifts, and aging infrastructure drivers, among other factors, continue to shift transmission needs away from large-scale, cross-system backbone projects toward projects that are driven by local needs and individual transmission owner criteria (also referred to as "supplemental projects").
- **Congestion and Local Reliability**: PJM's board-approved projects in 2018 will address market efficiency congestion and solve localized reliability criteria violations. The bottom-right figure reflects lower investments at 345 kV and above over the past four years and higher levels of transmission investments at voltages 230 kV and lower.

Approved RTEP Projects (December 31, 2018)



($M)	Active	Under Construction	In Service	Grand Total
Baseline Projects	$6,920	$1,659	$21,307	$29,887
Network Projects	$5,796	$244	$1,134	$7,173
Total	$12,716	$1,903	$22,441	$37,060

Approved Baseline Projects by Voltage (2015-2018)



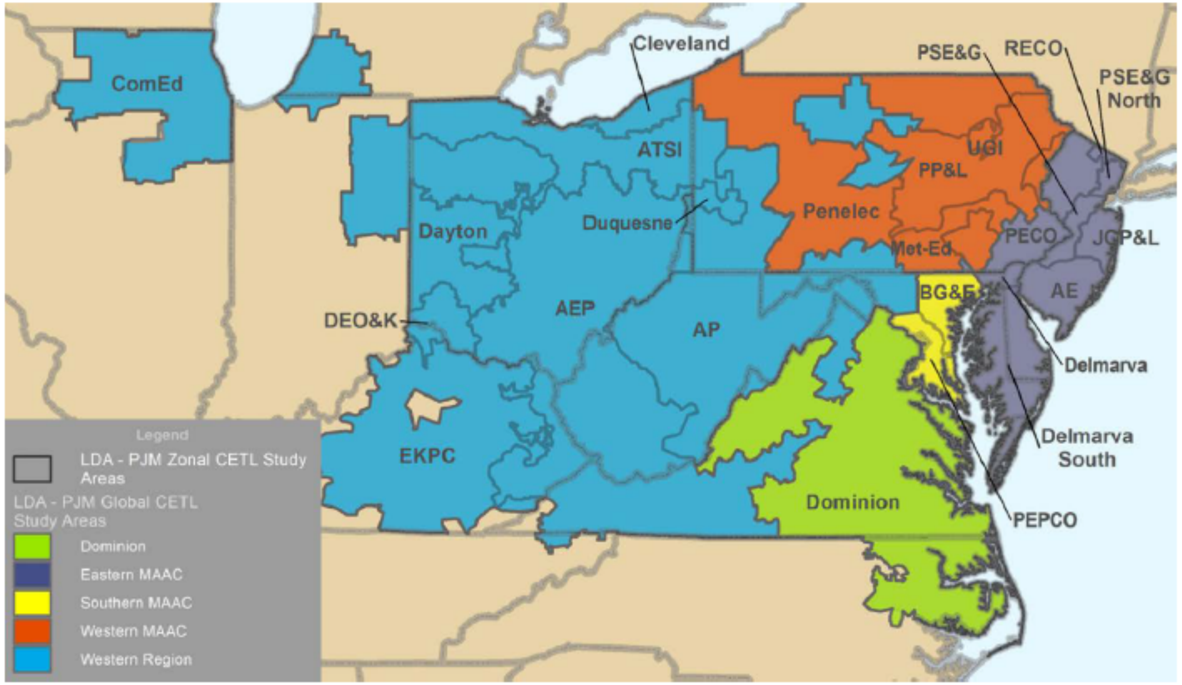
Sources: Benefits White Paper; 2018 RTEP

Transmission Topography and Investment (Cont'd)

Three Planning Paths in PJM

- The three paths for transmission in PJM include planning activities associated with (i) Baseline Projects, (ii) Supplemental Projects, and (iii) Customer-Funded Upgrades.
  1. **Baseline Projects** include projects planned for (i) reliability, (ii) operational performance, (iii) FERC Form No. 715 criteria, (iv) economic planning, and (v) public policy planning (state agreement approach).
  2. **Supplemental Projects** refer to transmission expansion or enhancements not needed to comply with PJM reliability, operational performance, FERC Form No. 715, economic criteria, or state agreement approach projects. Transmission owners plan supplemental projects in accordance with the Attachment M-3 Process. Projects planned through the Attachment M-3 Process include those that expand or enhance the transmission system and could include needs addressing transmission facilities at the end of their useful life, which, in accordance with good utility practice, is not determined by the facility's service life for accounting or depreciation purposes.
  3. **Customer-Funded Upgrades** refer to network upgrades, local upgrades, or merchant network upgrades identified pursuant to OATT Parts II, III, and VI and paid for by the interconnection customer or eligible customer or voluntarily undertaken by a new service customer in fulfillment of an upgrade request.

PJM Locational Deliverability Areas



Entity Name	Description
AE	Atlantic Electric
AEP	American Electric Power
APS	Allegheny Power
ATSI	American Transmission Systems, Incorporated
BGE	Baltimore Gas and Electric
Cleveland	Cleveland Area
ComEd	Commonwealth Edison
DAYTON	Dayton Power and Light
DEO&K	Duke Energy Ohio and Kentucky
DLCO	Duquesne Light Company
Dominion	Dominion Virginia Power
DPL	Delmarva Power and Light
Delmarva South	Southern Portion of DPL
Eastern Mid-Atlantic	Global area – JCP&L, PECO, PSE&G, AE, DPL, RECO
EKPC	East Kentucky Power Cooperative
JCP&L	Jersey Central Power and Light
METED	Metropolitan Edison
Mid-Atlantic	Global Area – Penelec, METED, JCP&L, PPL, PECO, PSE&G, BGE, PEPCO, AE, DPL, RECO
PECO	PECO
PENELEC	Pennsylvania Electric
PEPCO	Potomac Electric Power Company
PPL	PPL Electric Utilities Corporation, UGI
PSE&G	Public Service Electric and Gas
PSE&G North	Northern Portion of PSE&G
Southern Mid-Atlantic	Global area – BGE and PEPCO
Western Mid-Atlantic	Global Area – Penelec, METED, PPL
Western PJM	Global Area – APS, AEP, Dayton, DUQ, ComEd, ATSI, DEO&K, EKPC, OVEC

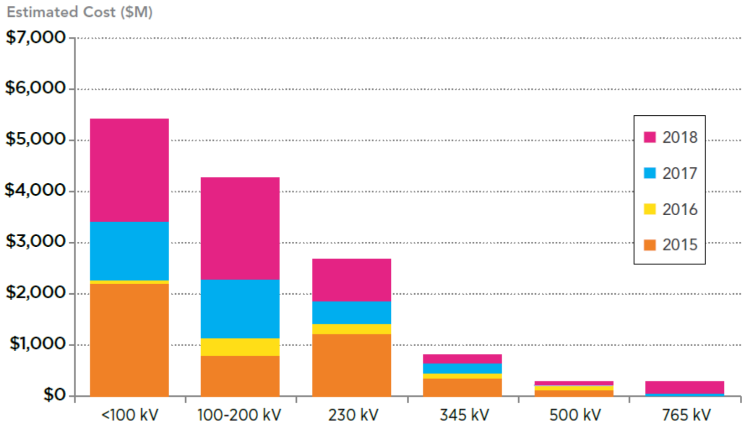
Source: Benefits White Paper

Transmission Topography and Investment (Cont'd)

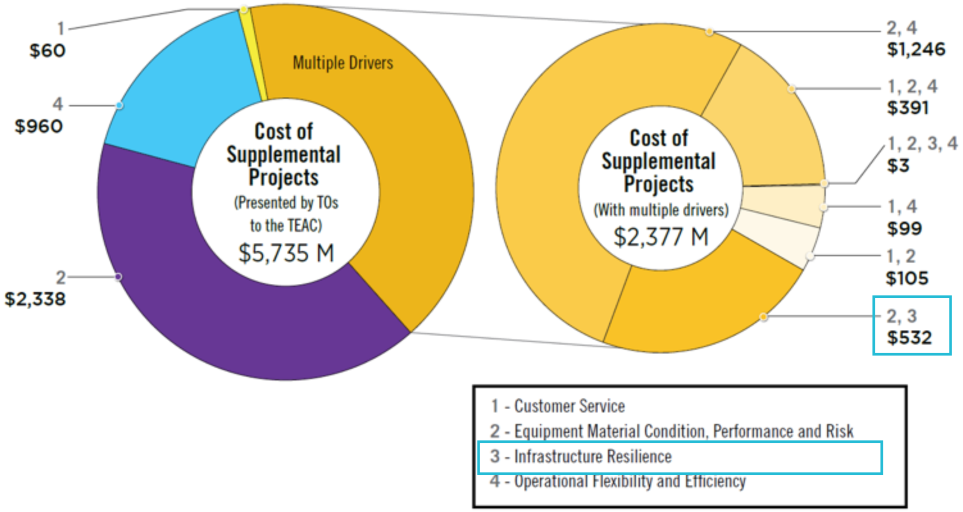
Shifting Transmission Project Drivers

- **Fewer Baseline Projects**: Baseline transmission projects in PJM that are driven by market efficiency and reliability have represented a declining portion of all projects in PJM in the past few years, and supplemental projects have comprised an increasing fraction of planned projects, representing nearly 73% of all projects in 2018. The next largest driver in 2018 was generator deactivations at 13%. Of the 51 baseline projects in PJM's 2018 RTEP, 49 are cost allocated to a single zone, indicating that projects are mostly driven by local need as opposed to PJM's intraregional needs.
  - **Supplemental Projects Defined**: Supplemental projects are not required for system reliability, operating performance, or market-efficiency economic criteria as defined by PJM. And, while not subject to PJM's board approval, each project is reviewed to ensure that it does not introduce other reliability criteria violations and is included in RTEP models.
  - **Drivers of Supplemental Projects**: Supplemental projects are identified by individual transmission owners to address local issues on the transmission owner's system. They tend to be at lower voltages compared to baseline projects, and they have five drivers:
    1. *Equipment Material Condition, Performance, and Risk*: Degraded equipment performance, material condition, obsolescence, equipment failure, employee and public safety, and environmental impact.
    2. *Operational Flexibility and Efficiency*: Optimizing system configuration, equipment duty cycles, and restoration capability; minimizing outages.
    3. *Infrastructure Resilience*: Improve system's ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event, including severe weather, geo-magnetic disturbances, physical and cyber security challenges, and critical infrastructure reduction. (Noted as a co-benefit of projects estimated to cost $532 million bottom right.)
    4. *Customer Service*: Service to new and existing customers. Interconnect new customer load. Address distribution load growth, customer outage exposure, and equipment loading.
    5. *Other Drivers*: Meet objectives not included in other definitions.

Supplemental Projects by Voltage (2015–2018)



2018 Supplemental Projects by Driver



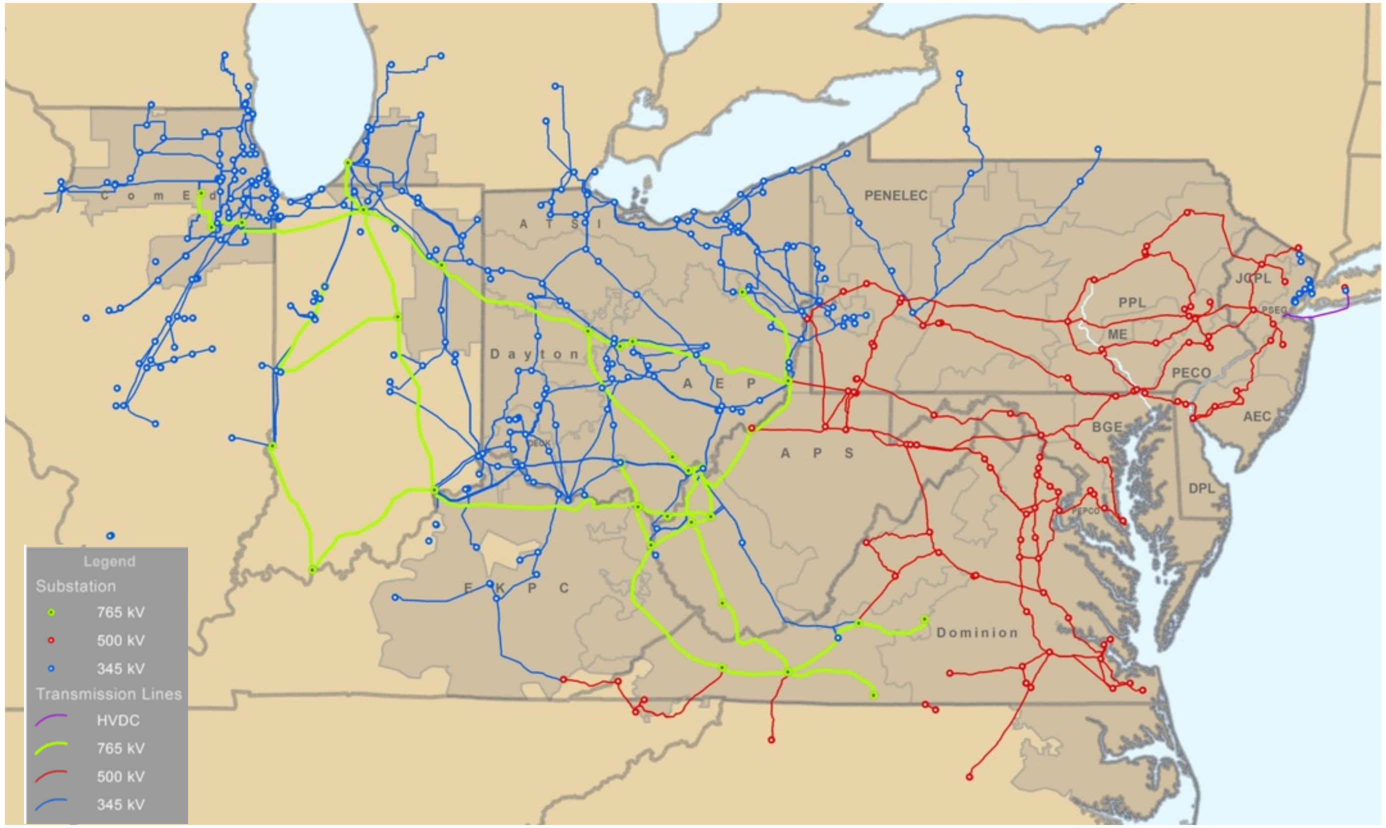
Source: Benefits White Paper

Transmission Topography and Investment (Cont’d)

Cost Allocation for Board-Approved Projects

- Per PJM, its FERC-approved cost allocation procedures reflect the regional “everyone benefits” reality.
- Reliability-Driven Projects
  - The cost for new reliability-driven transmission assets—approved by the PJM board of managers out of PJM’s RTEP process—that will operate at 765 kV and 500 kV or comprise double-circuit 345 kV construction are allocated 50% via load-ratio share across all transmission owner zones and 50% via distribution factors based on the impact of a new asset.
  - The socialized component of the allocation acknowledges that a definitive benefit from the elimination of a reliability criteria violation accrues to all consumers of electricity across the PJM footprint.
- Market Efficiency-Driven Projects
  - Board-approved market efficiency-driven RTEP projects that will operate at 765 kV and 500 kV or comprising double-circuit 345 kV construction are allocated 50% via load-ratio share and 50% via zonal benefit from decreased load payments.

PJM Transmission Backbone (December 31, 2018)



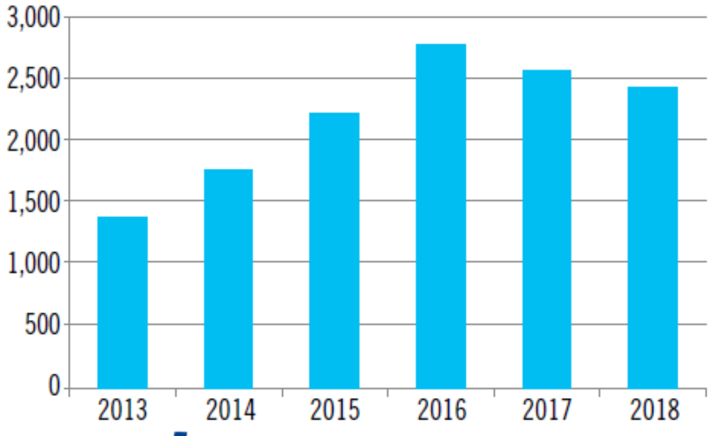
Source: Benefits White Paper

Transmission Topography and Investment (Cont'd)

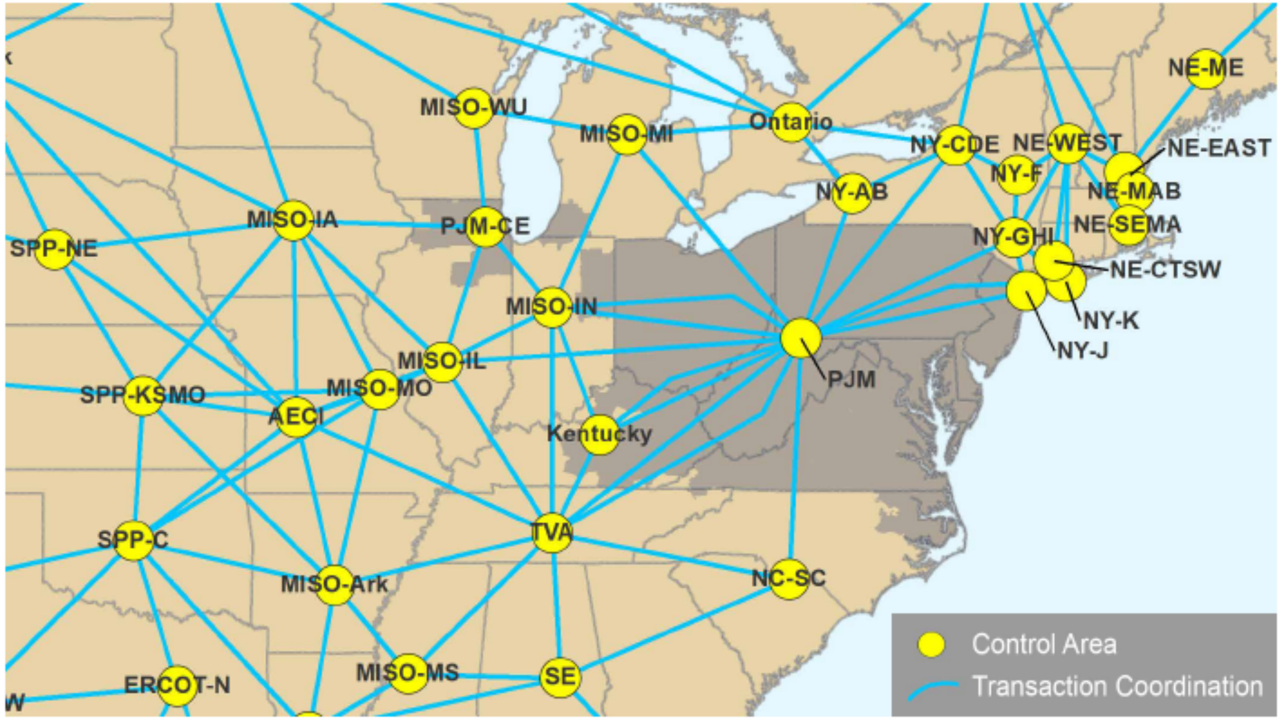
Interregional Transmission Coordination

- Interregional Power Sales
  - PJM has transmission lines connecting to adjoining systems:
    - North – NYISO, ISO-NE, Canadian utilities
    - West – MISO
    - South – Tennessee Valley Authority (TVA), Duke Energy Progress, Louisville Gas and Electric
  - Interregional transmission tie lines permit external generators to be "pseudo-tied" to PJM and participate in PJM's capacity, energy, and ancillary services markets as if they were inside PJM's footprint.
  - Since 2016, PJM has integrated more than 5,000 MWs of pseudo-tied generation into and out of PJM, accounting for the decrease in scheduled interchange since 2016, as shown below.

Average Hourly Schedule Interchange (Gross)



Interregional Power Sales and Purchases



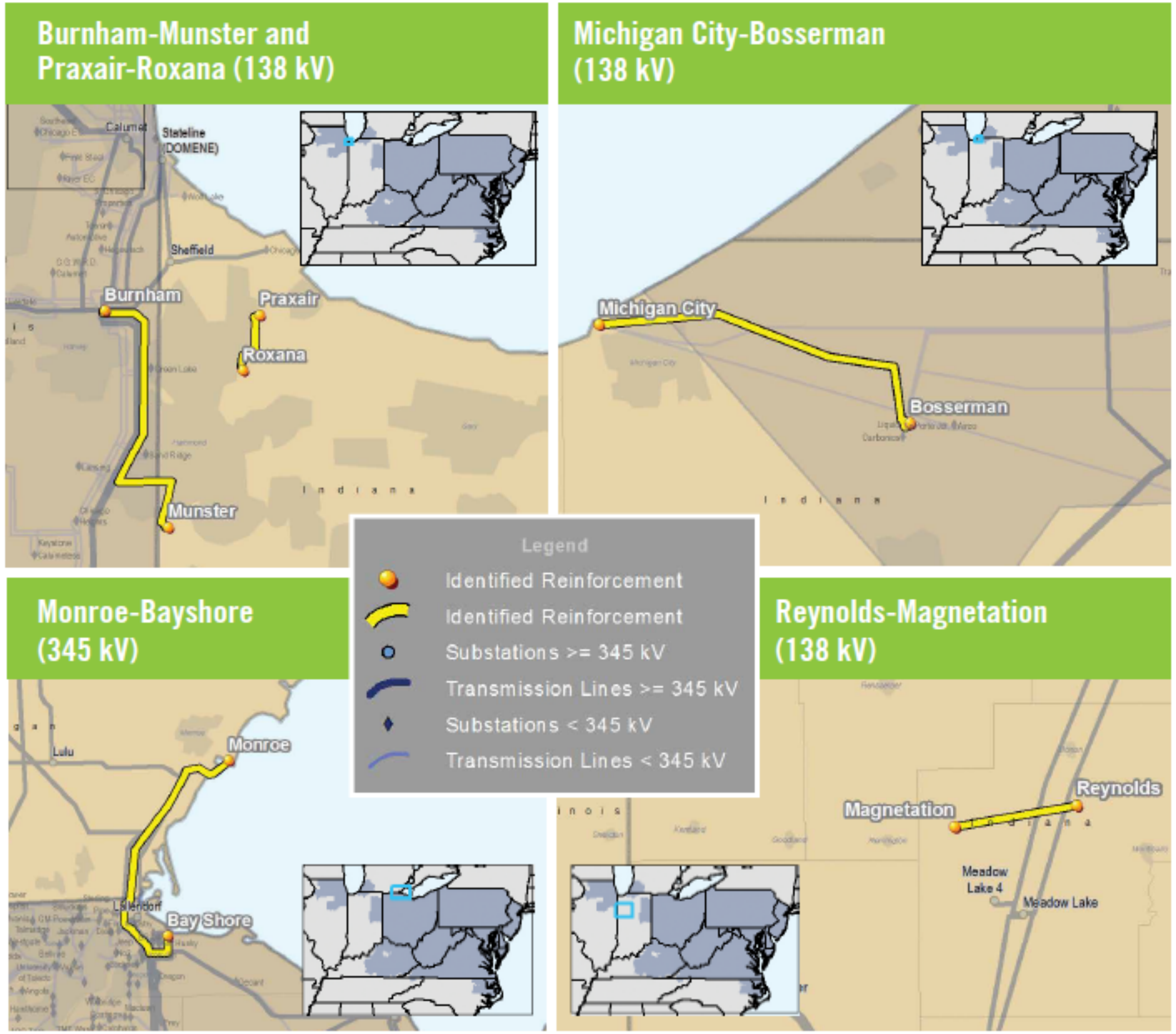
Source: Benefits White Paper

Transmission Topography and Investment (Cont'd)

Interregional Transmission Coordination (Cont'd)

- Targeted Market Efficiency Projects (TMEPs)
  - In December 2017, the PJM and MISO boards approved a portfolio of five TMEPs to address historical congestion along the PJM/MISO boundary.
  - TMEPs are focused on developing low-cost, short lead-time, high-impact projects to address market-to-market congestion.
  - TMEP projects must yield four-year market congestion savings that are equal to or greater than the estimated project capital cost.
  - The total capital cost for the five projects is approximately $20 million, with an estimated congestion savings benefit of $100 million over the first four years of commercial operation.
- Shared Reserve Activation with NPCC
  - PJM participates in reserve-sharing agreements with neighboring systems to assist both PJM and its neighbors with recovery from disturbances, including, in many instances, the loss of a generator greater than 500 MWs.
  - PJM's interregional agreement with the Northeast Power Coordinating Council (NPCC) includes provisions for shared reserves to help with disturbance control. This permits PJM to recover from an imbalance between supply and demand faster than with internal reserves alone. The help is reciprocal, and PJM provides NPCC with shared reserves when called upon.

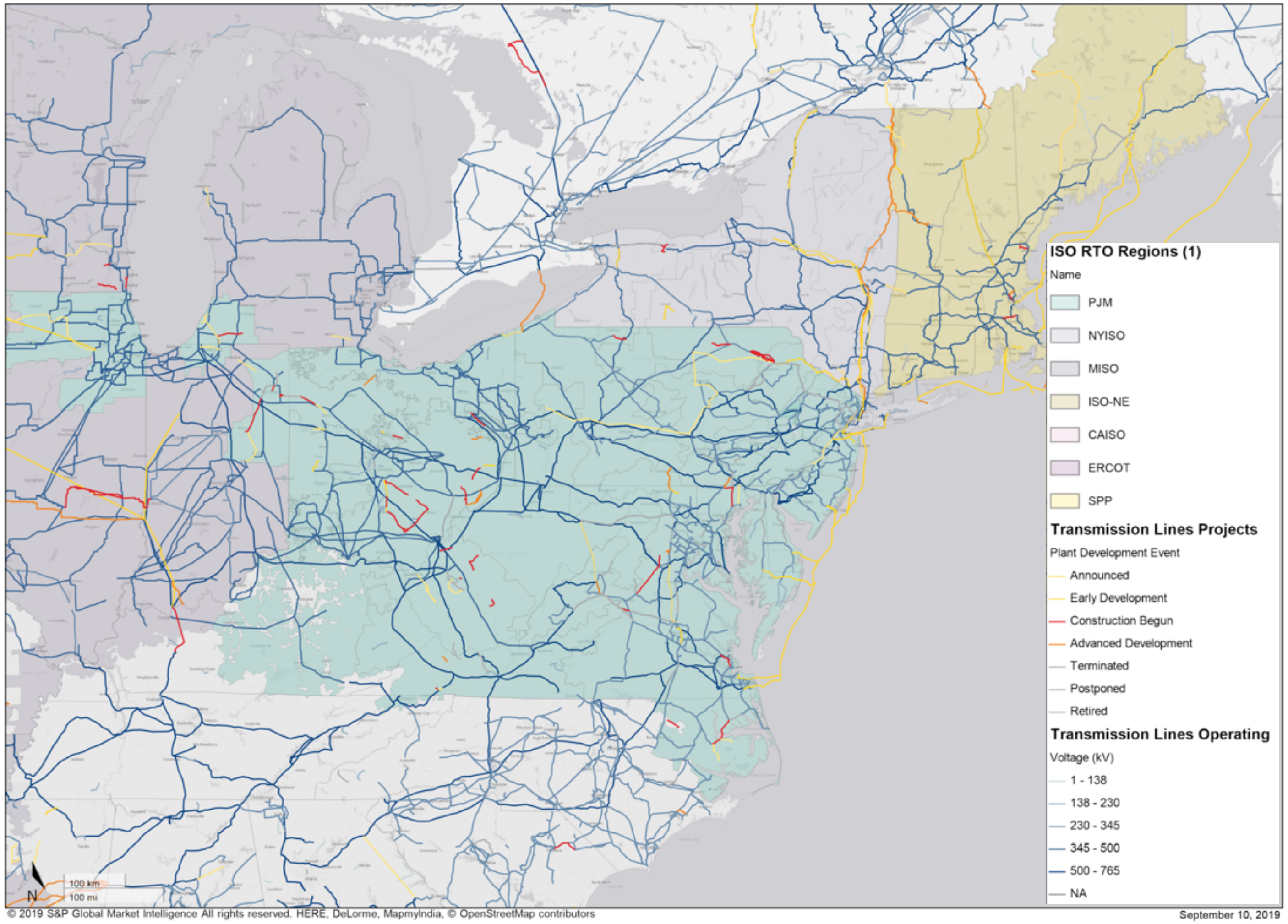
PJM/MISO Approved Targeted Market Efficiency Projects



Source: Benefits White Paper

Transmission Topography and Investment (Cont’d)

Selected PJM Transmission Lines



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September 10, 2019

Transmission Projects

- **Transfer Capability**: There is significant internal transfer capability within PJM, which allows for transfers between subregions. In addition, as described earlier, PJM is interconnected with various adjoining system operators.
- **Planned Lines**: According to NERC, approximately 848 miles of new transmission lines are either in planned stages or under construction as of late 2018, and an additional 25 miles are in the conceptual phase (see table below).
- **Reliability-Driven**: Of the 74 PJM projects cited by NERC, all are driven primarily by reliability, and economics/congestion is listed as the second driver for all projects.

Proposed Transmission Projects (Line Length in Circuit Miles) in PJM (as of Dec. 2018)

Operating Voltage Class (kV)	Conceptual	Planned	Under Construction
100–120	0	119.6	3
121–150	25.1	309.9	144.5
151–199	0	0	
200–299	0	192.6	55.7
300–399	0	12	11
400–599	0		
Grand Total	25.1	634.1	214.2

Source: NERC 2018 Electricity Supply & Demand

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Sources: NERC 2018 LTRA; NERC ES&D; S&P Global Market Intelligence

Transmission Topography and Investment (Cont'd)

Transmission Projects (Cont'd)

- **Merchant Projects**: Several transmission projects in PJM, most of which are merchant, are being developed to facilitate the delivery of renewable energy generated in remote areas to load centers. Progress has been limited, though, as many have only been announced or in early development for a number of years.
  - Atlantic Wind Connection: Though initially conceived as a project to move offshore wind to load centers on the East Coast, the project was "essentially divorced" from the nascent offshore wind industry in 2014 after the developer determined that the project could stand on its own as an outlet for congestion in New Jersey. Other benefits purported by the project's developer include "storm-hardening [New Jersey's] electric grid to make it stronger in the face of severe weather."
  - Poseidon Transmission: The 79-mile project, which will provide a connection from New Jersey to a substation in New York, is described as supplying up to 500 MWs from renewable energy from generating facilities in PJM to a load center in New York.
  - SOO Green Renewable Rail HVDC: The 349-mile project connecting Iowa to Illinois (MISO to PJM) will run along the route of an existing railroad, providing 2,100 MWs of capacity using 525 kV of high-voltage, direct-current technology that will be buried underground and connect wind power generated in Iowa to load centers further east.
- The following is a list of proposed projects as of year-end 2018:

Project Name	Project Owner(s)	Project Length (miles)	Project Voltage (kV)	From State	To State	From ISO	To ISO	Yr. in Svc.	Current Development Status	Project Type	Est. Const. Costs ($000)
Albion-South Goshen Transmission Line Rebuild	Indiana Michigan Power Company	21.00	138	IN	IN	PJM	PJM	2019	Announced	Upgrade	NA
Atlantic Wind Connection (New Jersey Link) Phase A	Trans-Elect Development Company, LLC	150.00	320	NJ	NJ	PJM	PJM	NA	Early Development	New	1,800,000
Atlantic Wind Connection – Bay Link	Trans-Elect Development Company, LLC	38.00	320	NJ	DE	PJM	PJM	NA	Early Development	New	NA
Atlantic Wind Connection (New Jersey Link) Phase A	Trans-Elect Development Company, LLC	606.00	320	NJ	VA	PJM	PJM	NA	Early Development	New	NA
Barnesville-Summerfield 138 kV Transmission Line Rebuild	AEP Ohio Transmission Company, Inc.	16.00	138	OH	OH	PJM	PJM	2020	Construction Begun	Rebuild	NA
Beury Mountain to Brackens Creek 138 kV Line (Fayette County Area)	AEP West Virginia Transmission Co.	12.00	138	WV	WV	PJM	PJM	NA	Construction Begun	New	NA
Boone County Area Improvements (Boone - Cabin Creek) (Phase 1)	AEP West Virginia Transmission Co., Appalachian Power Co.	16.00	138	WV	WV	PJM	PJM	2019	Announced	Rebuild	NA
Boone County Area Improvements (Boone - South Charleston) (Phase 2)	AEP West Virginia Transmission Co., Appalachian Power Co.	18.00	69	WV	WV	PJM	PJM	2020	Announced	Rebuild	NA
Bristers to Ladysmith Upgrade	Virginia Electric and Power Company	37.00	500	VA	VA	PJM	PJM	2023	Announced	Upgrade	110,250
Carrollton-Sunnyside 138 kV Transmission Line Rebuild	AEP Ohio Transmission Company, Inc.	20.00	138	OH	OH	PJM	PJM	2019	Construction Begun	Rebuild	50,000
Cass County Area Improvements (Kenzie Creek to Corey)	Indiana Michigan Power Company	29.00	138	MI	MI	PJM	PJM	2019	Construction Begun	Rebuild	NA
Clendenin – Walton Area Improvements (Part 2)	AEP Trans. Holding Co., LLC, Evergy	23.00	138	WV	WV	PJM	PJM	2019	Construction Begun	New	NA
Compass (Phase 1)	PPL Electric Utilities Corporation	95.00	345	NY	PA	NYISO	PJM	2023	Early Development	New	600,000

Note: Includes projects 10 miles or greater and 115 kV and higher and projects in announced, early development, advanced development, and under construction statuses. Data accessed June 2019.
Sources: S&P Global Market Intelligence; transmission project websites; NERC ES&D

Transmission Topography and Investment (Cont’d)

Transmission Projects (Cont’d)

Project Name	Project Owner(s)	Project Length (miles)	Project Voltage (kV)	From State	To State	From ISO	To ISO	Yr. in Svc.	Current Development Status	Project Type	Est. Const. Costs ($000)
Compass Transmission Line (Segment 2)	PPL Electric Utilities Corporation	380.00	345	PA	PA	PJM	PJM	NA	Announced	New	NA
Delano-Scioto Trail 138 kV Rebuild	AEP Ohio Transmission Company, Inc.	12.00	138	OH	OH	PJM	PJM	NA	Construction Begun	Rebuild	NA
Dennison – Yager-Desert Road Rebuild (Eastern Ohio Tri-County)	AEP Ohio Transmission Company, Inc.	15.00	138	OH	OH	PJM	PJM	NA	Adv. Development	Rebuild	NA
Dooms To Cunningham 500 kV Rebuild	Virginia Electric and Power Company	33.00	500	VA	VA	PJM	PJM	2019	Construction Begun	Rebuild	65,000
Dooms – Valley Rebuild Transmission Line	Virginia Electric and Power Company	18.00	500	VA	VA	PJM	PJM	2020	Adv. Development	Rebuild	55,900
East Towanda-South Troy Transmission Rebuild	Trans-Allegheny Interstate Line Company	20.00	230	PA	PA	PJM	PJM	NA	Construction Begun	Rebuild	40,000
Edenton-Trowbridge 230 kV Conversion	Dominion Energy, Inc.	34.00	230	NC	NC	PJM	PJM	NA	Construction Begun	Upgrade	NA
Elmont to Ladysmith Rebuild	Virginia Electric and Power Company	26.00	500	VA	VA	PJM	PJM	2022	Announced	Rebuild	87,000
Erie West to Ashtabula 345 kV Line	Northeast Transmission Development	22.00	345	PA	OH	PJM	PJM	NA	Announced	New	44,900
Fostoria-Fremont Transmission Line Rebuild (Buckley Road-Fremont Center)	AEP Ohio Transmission Company, Inc.	15.00	138	OH	OH	PJM	PJM	2020	Adv. Development	Rebuild	NA
Fulton-Windfall Switch 138 kV Rebuild Transmission Line	AEP Ohio Transmission Company, Inc.	10.00	138	OH	OH	PJM	PJM	2020	Early Development	Rebuild	15,600
Furnace Run-Conastone 230 kV Transmission Line (9A) (Transource IEC)	AEP Trans. Holding Co., LLC, Evergy.	16.00	230	PA	MD	PJM	PJM	2020	Adv. Development	New	NA
Glencoe - Speidel 138 kV Rebuild Transmission Line	AEP Ohio Transmission Company, Inc.	13.00	138	OH	OH	PJM	PJM	2020	Early Development	Rebuild	26,042
Good Hope-Harrison 138 kV Transmission Line (Rebuild)	AEP Ohio Transmission Company, Inc.	30.00	138	OH	OH	PJM	PJM	NA	Construction Begun	Rebuild	NA
Granger - Benton Harbor Transmission Line Rebuild	Indiana Michigan Power Company	46.00	138	IN	MI	PJM	PJM	2022	Announced	Rebuild	NA
Green Power Express (Plano to Hazleton)	ITC Green Power Express, LLC	215.00	765	IL	IA	PJM	MISO	2020	Early Development	New	NA
Harrison-Ross 138 kV Transmission Line Rebuild	AEP Ohio Transmission Company, Inc.	40.00	138	OH	OH	PJM	PJM	NA	Early Development	Rebuild	NA
Haviland – North Delphos Rebuild Transmission Line	American Electric Power Company, Inc.	17.00	138	OH	OH	PJM	PJM	NA	Construction Begun	Rebuild	20,000
Hedding Road - Fulton 138 kV Transmission Line Rebuild	AEP Ohio Transmission Company, Inc.	10.00	138	OH	OH	PJM	PJM	2019	Construction Begun	Rebuild	14,759
Jackson-Ross County Area Improvements Rebuild Line	AEP Ohio Transmission Company, Inc., Ohio Power Company	35.00	138	OH	OH	PJM	PJM	2019	Early Development	Rebuild	NA
Lackawanna-North Meshoppen 230 kV Transmission Line Rebuild	Mid-Atlantic Interstate Transmission, LLC	27.00	230	PA	PA	PJM	PJM	2020	Construction Begun	Rebuild	64,200
Lake Erie Connector	ITC Holdings Corp.	73.00	320	PA	ON	PJM	IESO	2023	Adv. Development	New	1,000,000
Lakeside to Chesterfield Rebuild	Virginia Electric and Power Company	21.00	230	VA	VA	PJM	PJM	2020	Early Development	Rebuild	31,000

Note: Includes projects 10 miles or greater and 115 kV and higher and projects in announced, early development, advanced development, and under construction statuses.

Sources: S&P Global Market Intelligence; NERC ES&D

Transmission Topography and Investment (Cont'd)

Transmission Projects (Cont'd)

Project Name	Project Owner(s)	Project Length (miles)	Project Voltage (kV)	From State	To State	From ISO	To ISO	Yr. in Svc.	Current Development Status	Project Type	Est. Const. Costs ($000)
Leon-Ripley 138 kV Transmission Rebuild	AEP West Virginia Transmission Company, Inc., Appalachian Power Co.	14.00	138	WV	WV	PJM	PJM	2019	Construction Begun	Rebuild	NA
Lincoln – Logan Power Upgrade	AEP West Virginia Transmission Company, Inc.	24.00	138	WV	WV	PJM	PJM	2021	Announced	Upgrade	NA
Mackeys to Creswell Rebuild Transmission Line	Dominion Energy, Inc.	14.00	115	NC	NC	PJM	PJM	NA	Announced	Rebuild	NA
McClung to Brackens Creek 138 kV Rebuild (Fayette County Area)	AEP West Virginia Transmission Company, Inc.	14.00	138	WV	WV	PJM	PJM	NA	Construction Begun	Rebuild	NA
Metuchen to Trenton 230 kV Transmission Line Rebuild	Public Service Electric and Gas Co.	30.00	230	NJ	NJ	PJM	PJM	2022	Announced	Rebuild	NA
Monmouth County Reliability	Jersey Central Power & Light Company	10.00	230	NJ	NJ	PJM	PJM	2019	Early Development	New	NA
Mt. Storm-Valley 500 kV Rebuild	Virginia Electric and Power Company	64.00	500	WV	VA	PJM	PJM	2021	Announced	Rebuild	285,000
Muncie - Marion Transmission Line Rebuild	Indiana Michigan Power Company	20.00	138	IN	IN	PJM	PJM	2021	Announced	Rebuild	NA
North Delphos – Rockhill Rebuild Transmission Line	American Electric Power Company, Inc.	16.00	138	OH	OH	PJM	PJM	2020	Announced	Rebuild	24,500
Northeast Transmission System Improvement (Conastone- Raphael)	Baltimore Gas and Electric Company	29.00	230	MD	MD	PJM	PJM	NA	Construction Begun	Upgrade	111,000
Pantego-Trowbridge Reliability	Dominion Energy, Inc.	22.00	115	NC	NC	PJM	PJM	NA	Announced	New	NA
Peach Bottom to Old Post 230 kV Transmission Line	ITC Holdings Corp.	26.00	230	PA	MD	PJM	PJM	2021	Announced	New	73,600
Pierce Brook-Lewis Run Transmission Line	Mid-Atlantic Interstate Transmission, LLC	16.00	230	PA	PA	PJM	PJM	NA	Construction Begun	New	15,800
Poseidon Transmission	Anbaric Development Partners, LLC, Exelon Transmission Company, LLC	79.00	200	NY	NJ	NYISO	PJM	2021	Early Development	New	NA
Poston-Hocking 138 kV Transmission Line Rebuild	AEP Ohio Transmission Company, Inc.	16.00	138	OH	OH	PJM	PJM	NA	Construction Begun	Rebuild	9,278
Poston-Lick 138 kV Rebuild Line	AEP Ohio Transmission Company, Inc.	22.00	138	OH	OH	PJM	PJM	NA	Construction Begun	Rebuild	19,680
Remington CT to Warrenton (Warrenton Wheeler Gainesville 230 kV)	Virginia Electric and Power Company	12.00	230	VA	VA	PJM	PJM	NA	Construction Begun	Upgrade	NA
Remington to Gordonsville 230 kV Rebuild	Virginia Electric and Power Company	38.00	230	VA	VA	PJM	PJM	2020	Construction Begun	Rebuild	NA
Rice-Ringgold 230 kV Transmission Line (9A) (Transource IEC)	AEP Trans. Holding Co., LLC, Evergy	29.00	230	PA	NA	PJM	PJM	2020	Adv. Development	New	NA
Ringgold to Catoctin 230 kV Rebuild	Potomac Edison Company	10.00	230	NA	MD	PJM	PJM	2020	Early Development	Rebuild	NA
Roanoke – Marion Transmission Rebuild Line	Indiana Michigan Power Company	37.00	138	IN	IN	PJM	PJM	2020	Construction Begun	Rebuild	85,000
Scotland Neck – South Justice Branch Reliability	Dominion Energy, Inc.	15.00	115	NC	NC	PJM	PJM	NA	Construction Begun	New	NA
Skiffes Creek-Whealton 230 kV Line	Virginia Electric and Power Company	20.00	230	VA	VA	PJM	PJM	NA	Construction Begun	New	72,180

Note: Includes projects 10 miles or greater and 115 kV and higher and projects in announced, early development, advanced development, and under construction statuses.
Sources: S&P Global Market Intelligence; NERC ES&D

Transmission Topography and Investment (Cont'd)

Transmission Projects (Cont'd)

Project Name	Project Owner(s)	Project Length (miles)	Project Voltage (kV)	From State	To State	From ISO	To ISO	Yr. in Svc.	Current Development Status	Project Type	Est. Const. Costs ($000)
SOO Green Renewable Rail HVDC Transmission	Soo Green Renewable Rail Llc	349.00	525	IA	IL	MISO	PJM	2024	Announced	New	2,500,000
Southeast Ohio Area Improvements (Bell Ridge-Devola)	AEP Ohio Transmission Company, Inc.	10.00	138	OH	OH	PJM	PJM	2021	Adv. Development	Rebuild	NA
Southeast Ohio Area Improvements (Macksburg-Devola Rebuild)	AEP Ohio Transmission Company, Inc., Buckeye Power, Inc., Ohio Power Company, Washington Electric Cooperative, Inc.	17.00	138	Ohio	Ohio	PJM	PJM	2019	Adv. Development	Rebuild	30,000
Southeast Ohio Area Improvements (Rouse-Bell Ridge)	AEP Ohio Transmission Company, Inc.	13.00	138	OH	OH	PJM	PJM	2021	Adv. Development	Rebuild	NA
Trenton to Burlington 230 kV Transmission Line Rebuild	Public Service Electric and Gas Company	22.00	230	NJ	NJ	PJM	PJM	2022	Announced	Rebuild	NA
Vint Hill-Wheeler-Gainesville Upgrade (Warrenton Wheeler Gainesville 230 kV)	Virginia Electric and Power Company	12.00	230	VA	VA	PJM	PJM	NA	Adv. Development	Upgrade	NA
Wapakoneta Area Improvements Line	AEP Ohio Transmission Company, Inc.	15.00	138	OH	OH	PJM	PJM	2021	Announced	New	NA
West Milton-Eldean 138 kV Transmission Line	Dayton Power and Light Company	17.00	138	OH	OH	PJM	PJM	2022	Early Development	New	16,000

Note: Includes projects 10 miles or greater and 115 kV and higher and projects in announced, early development, advanced development, and under construction statuses.

Sources: S&P Global Market Intelligence; NERC ES&D

Resilience Issues

General Resilience Issues and Approach

- **Context**: The area covered by PJM is a broad area with a diverse array of industries and weather. As a frame of reference for the potential economic impact of a resilience event, PJM's 2018 annual GDP for those states in its footprint was $23.5 trillion.*
- **Cold Snap Analysis**: PJM conducted a stress test analysis, examining resilience during a 14-day cold snap under various scenarios of generator retirements, pipeline disruptions, gas availability, and forced outages. It found:
  - With announced retirements, its system remains reliable under extreme winter-load scenarios.
  - However, with accelerated retirements and extreme winter load, its system is at risk for voltage reduction and localized manual load shed, in addition to demand response deployment and reserve shortage.
  - With extended extreme cold weather, the key variables become non-firm gas availability, pipeline configuration, on-site fuel inventory, and oil deliverability.
- **Role of Transmission Planning**: PJM uses its transmission planning process to address resilience, with a view to provide diverse resources to effectively respond to events through real-time operations. Further, PJM has initiated efforts to implement RTEP process criteria and metrics in order to enhance grid resilience beyond that in place today and suggest that resilience criteria could be incorporated in the planning process through three decision-making approaches:
  - Do no harm, so that the solution to an identified reliability criteria violation does not introduce new resilience issues.
  - Leverage project opportunities already identified under reliability, market-efficiency needs, or public policy needs to enhance resilience.
  - Respond proactively with new projects to mitigate resilience risks.
- **Other Initiatives**: While PJM continues to pursue formal implementation of these transmission planning approaches, parallel transmission resilience initiatives continue in several areas: spare transformer need, phasor measurement unit implementation and cascading event analysis tool development (more on the following page).

Reported Electric Disturbance Events Affecting PJM (2017–April 2019)

Cause	2017	2018	2019 YTD
Fuel Supply Deficiency	0	0	0
Severe Weather	9	25	8
Vandalism	2	1	3
Actual Physical Attack	0	0	1
Suspicious Activity	0	2	0
Transmission Interruption	1	1	2
Generation Inadequacy	0	0	0
System Operations	0	10	4

Note: For multiple causes, classified under one only.
Sources: DOE OE-417; ScottMadden analysis

*Note: Figure applies to states of DE, IL, IN, KY, MD, MI, NC, NJ, OH, PA, TN, VA, WV, and DC.
Sources: PJM Resilience Testimony; Bureau of Economic Analysis; EIPC Study

Resilience Issues (Cont'd)

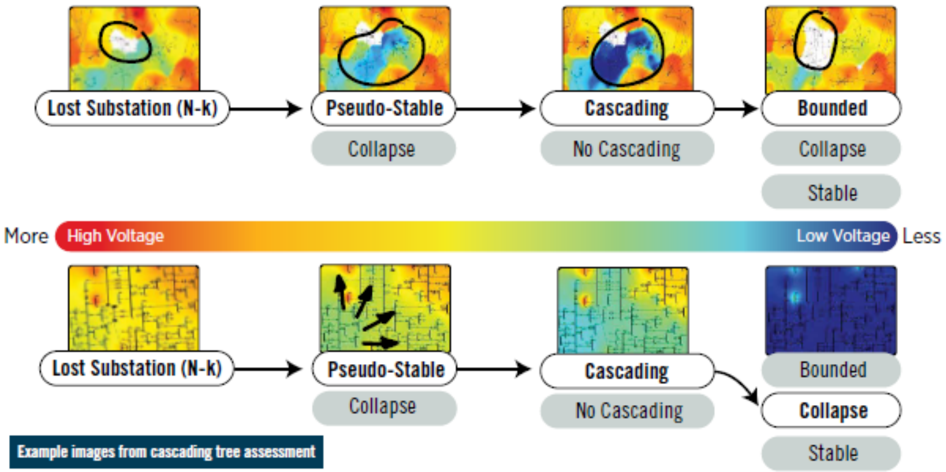
Planning for Resilience in the RTEP Process

- PJM's operations, planning, markets, physical security, and cybersecurity functions are part of ongoing collaborative, organization-wide efforts to establish processes, develop tools, and enhance communication linkages to maximize grid resilience.
- From a transmission perspective, PJM has initiated efforts to implement RTEP process criteria and metrics to enhance grid resilience beyond that in place today by virtue of compliance with NERC standards TPL-001-4, TPL-007-1, and CIP-014. PJM is working with its members to incorporate resilience into the transmission planning process.

Other PJM Resilience Initiatives

- **Spare transformers**: Beginning in 2006, PJM identified the need to have spare transformers as a reliability concern, and PJM runs a probabilistic risk assessment (PRA) model biennially to identify potential risks of failure, potential replacement costs, and the installation time for new transformers.
- **Deployment of phasor measurement units**: With the aid of a $14 million U.S. Department of Energy stimulus grant, PJM and its member transmission owners have installed more than 400 phasor measurement units (PMUs) in more than 120 substations in 10 states, improving the granularity and quality of situational awareness on the system.
- **Cascading event analysis tool**: Current efforts have narrowed into the development of a new planning tool and methodology, using a "cascading trees" event analysis, which complements existing studies by simulating and testing system resilience (see diagram at right).
  - The methodology provides a way to simulate severe contingency events, such as the loss of a substation at extreme conditions, to quantify the probability of a cascading system and the loss of load and generation, and to determine if the event is bounded, unbounded, or unstable.
  - Monte Carlo analysis is then performed to identify the repeat offenders or lines/substations that are impacted more frequently and reinforce those facilities.
  - Beyond extreme events, PJM uses this methodology to compare competing projects to measure which one increases or decreases the probability of cascading or resilience. PJM has adopted three approaches to integrating resilience into the RTEP and the RTEP decision-making process.
  - Further development of the resilience process and how it fits into the RTEP process will continue into 2019 by way of PJM planning committee meetings.

Cascading Tree Concept



Source: PJM

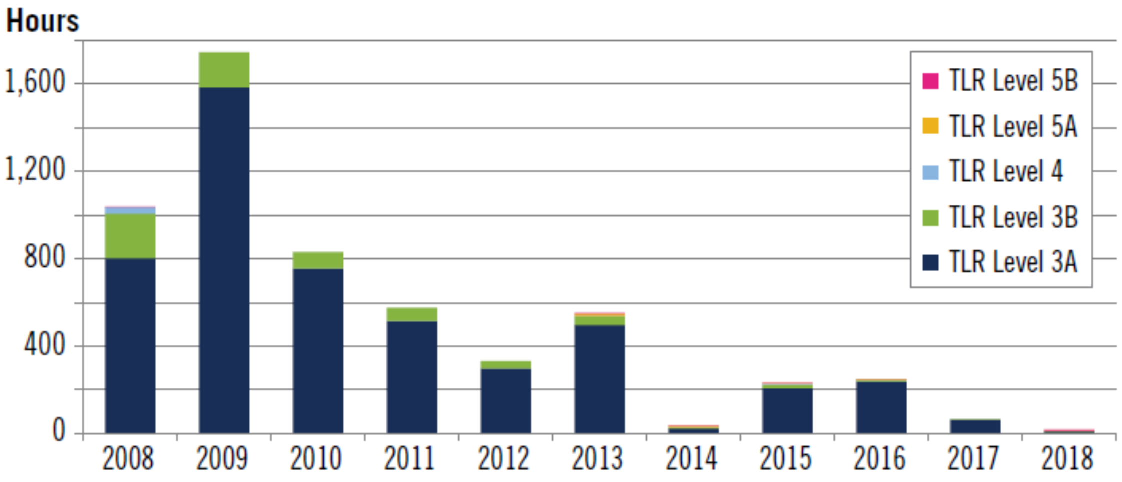
Source: Benefits White Paper

Resilience Issues (Cont'd)

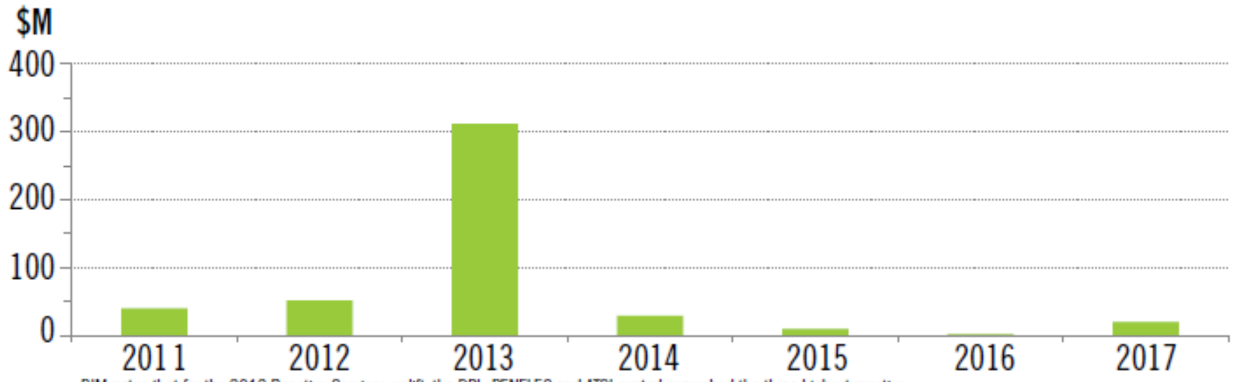
Benefits of Transmission Enhancements

- PJM has observed positive trends in the number of transmission loading relief (TLR) procedure hours (top right), the number of voltage actions (bottom right), and a decline in annual reactive services uplift charges (bottom left)—all of which PJM attributes as benefits resulting from recent investments in the transmission system.
  - TLR: TLR procedures curtail power sales between transmission entities to manage cross-border transmission constraints. The increasing robustness of the transmission system and improving interregional interoperability allows PJM to manage the transmission system using fewer TLR procedures.
  - Voltage actions: PJM's regional planning process has always included system analysis under peak-load conditions, during which low-voltage criteria violations have been identified and solutions implemented over time. Identifying high-voltage conditions has been a much more recent system phenomenon, typically during periods of low customer demand.

Transmission Loading Relief (TLR) Procedure Hours (2008–2018)

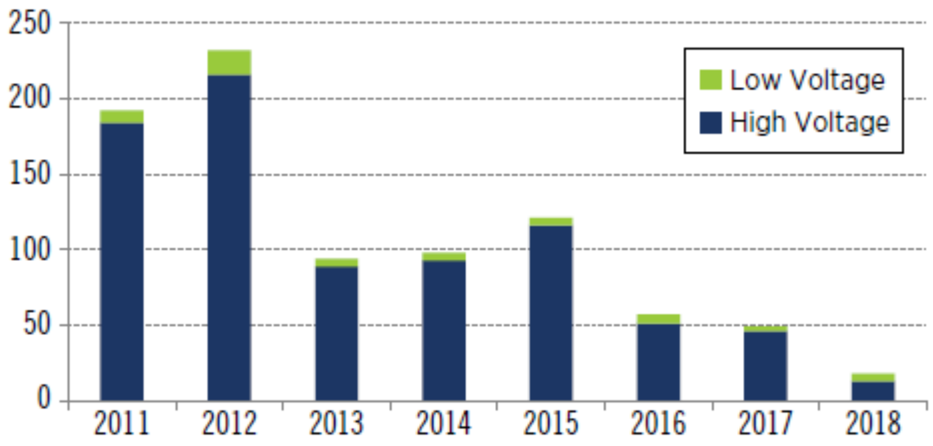


Annual Reactive Services Uplift Charges (2011–2018)



PJM notes that for the 2013 Reactive Services uplift, the DPL, PENELEC and ATSI control zones had the three highest reactive local voltage support rates: $2.538, $1.900 and $0.690 per MWh.

Voltage Actions on the PJM System (2011–2018)



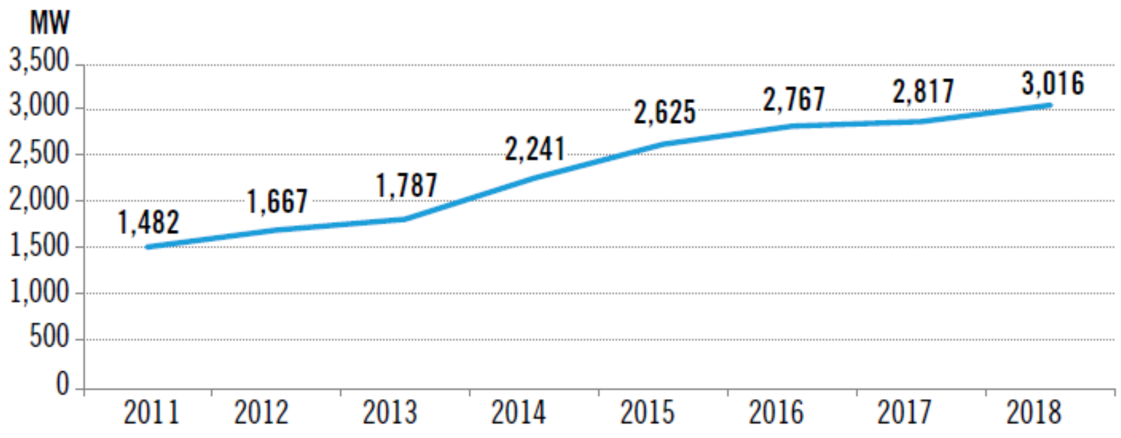
Source: Benefits White Paper

Resilience Issues (Cont'd)

Improved Transfer Interface Margins

- PJM further reports that it has observed interconnection reliability operating limits (IROL) operating margins have increased as a result of the additional transfer capability provided by new transmission assets, providing the operator with additional flexibility to exchange power with neighboring regions as needed to address reliability and resilience needs. Greater transfer capability increases economic efficiency through greater opportunity for bilateral power purchases and sales by participants in PJM markets.
- The average margin in PJM across all IROL interfaces was 1,482 MWs in 2011, which more than doubled to an average margin of 3,016 MWs in 2018 (see figure below). While generation patterns shift over time and impact the margin, new transmission enhancements have contributed to this increase as well.

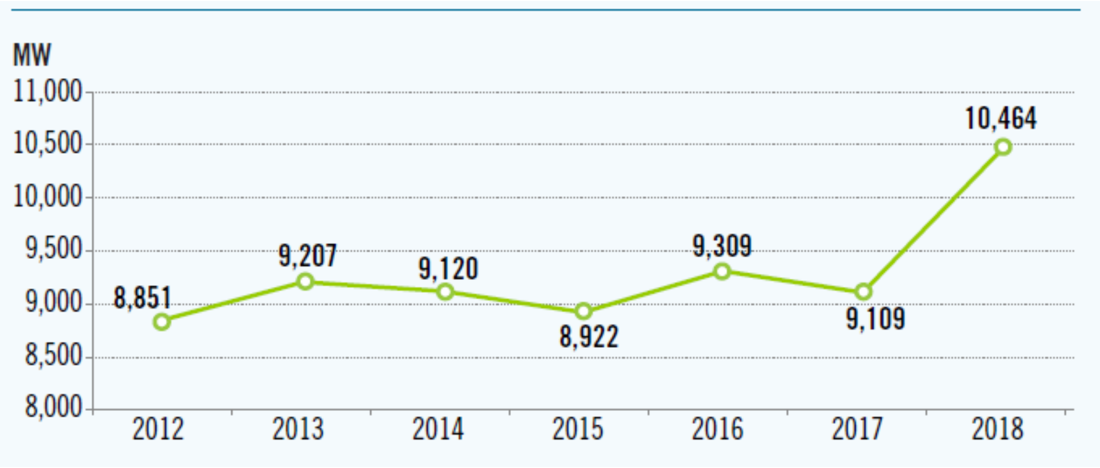
PJM IROL Margin Improvement (2011–2018)



Case Study: Eastern Transfer Interface Limit Margin

- PJM's Eastern Interface offers a case study that demonstrates how transmission enhancements have increased the amount of power that can be transferred across it. The ability to transfer power across that interface was boosted by the completion of the Susquehanna-Lackawanna-Hopatcong-Roseland 500 kV transmission line.
- The completion of the line in May 2015, coupled with other lower-voltage transmission enhancements in eastern PJM, has increased the transfer capability across the Eastern Interface since 2015. Between 2012 and 2018, the maximum annual Eastern Interface IROL transfer capability increased from 8,851 MWs to 10,464 MWs.

Maximum Annual Eastern Transfer Interface IROL (2012–2018)



Source: Benefits White Paper

Resilience Issues (Cont'd)

Selected Major Bulk Power Events Affecting PJM	
Event	**Description**
Northeast Snowstorm (Oct. 29-30, 2011)	• An unprecedented fall snowstorm hit the northeastern U.S., breaking all previous October records. Parts of New York, New Jersey, and Pennsylvania also received well over a foot of snow. The quantity of snow held by the unusually top-heavy trees, coupled with the soft, wet ground, resulted in a great number of healthy trees, most outside of utility rights-of-way, being uprooted and falling onto distribution and transmission lines. • On the morning of October 30, near the end of the storm, more than 3.2 million homes and businesses were without power. Thousands were without power for more than a week, some for as long as eleven days. Estimates put storm costs between approximately \$1 billion and \$3 billion.
Polar Vortex (Jan. 2014)	• In early January of 2014, the Midwest, South Central, and East Coast regions of North America experienced a weather condition known as a polar vortex, where extreme cold weather conditions occurred in lower latitudes than normal, resulting in temperatures 20 to 30° F below average. NYISO recorded its all-time peak winter load on Jan. 7. • For PJM, nearly 2 GWs of cold weather generation outages were reported, with about 770 MWs related to fuel-gelling issues. Some dual-fuel units experienced challenges ranging from a lack of natural gas required for starting the alternate fuel to fuel freezing in the injectors. Outages related to curtailments and interruptions of natural gas delivery were the significant contributor of the NPCC generator outages. These outages totaled a maximum of 3,296 MWs of generators, and they significantly impacted NPCC's generation resources starting at approximately 10:00 a.m. on Jan. 7, 2014.
Winter Storms Riley and Quinn (March 1-20, 2018)	• In March 2018, winter storm Riley, a powerful nor'easter caused major impacts in the Northeastern, Mid-Atlantic, and Southeastern U.S., bringing hurricane force winds to coastal New England and producing more than two feet of snow in some areas. Although the most severe damage was caused by flooding and snow, unusually high tides and storm surges along the coast, wind, and downed trees caused very large inland power outages. Recovery efforts were also hampered as a second nor'easter, winter storm Quinn, began to impact the area just a few days later. • At least two million customers in 13 states lost power at some point during the storm. The storm was called a "bomb cyclone" because of how quickly the pressure dropped—24 millibars in 24 hours.

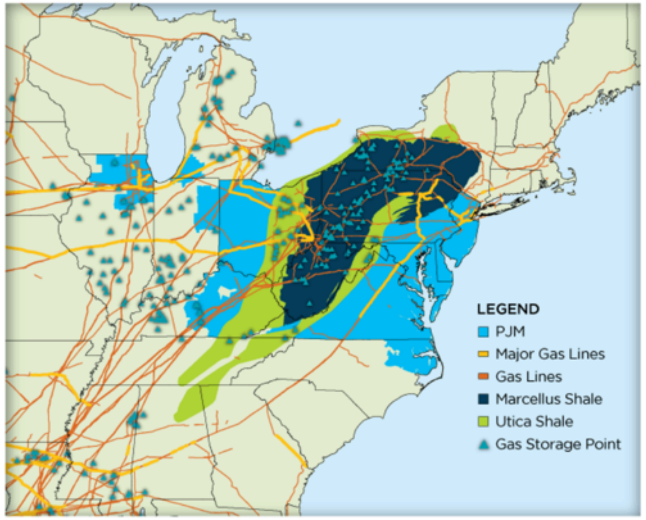
Sources: PJM Polar Vortex Report; PPUC Riley-Quinn Report

Resilience Issues (Cont'd)

Gas Infrastructure Dependency Analyses

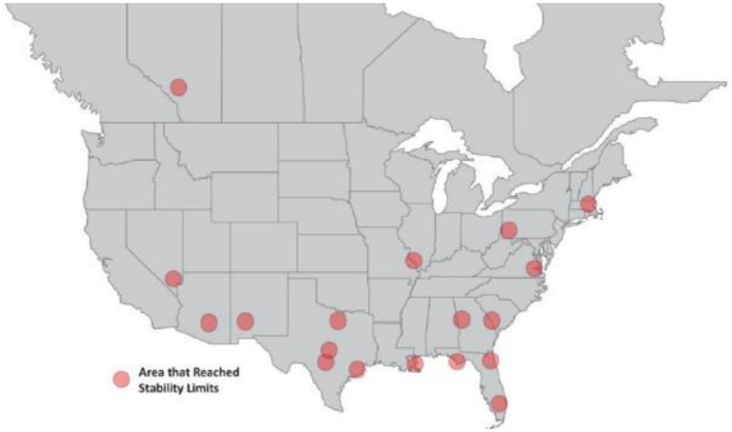
- **Studying Effects of Large Gas Fleet**: With a large and growing set of natural gas-fired resources, PJM has been studying gas-electric coordination and potential effects of resilience events.
  - NERC conducted a special study of potential reliability impacts of disruption of natural gas delivery. 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 PJM's footprint: southern coastal Virginia and western Pennsylvania, near the borders with Maryland and Ohio (see map lower right).
  - 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 some areas with "affected generation" in PJM in high-winter peak-load conditions in 2023, particularly in the Delmarva Peninsula, Maryland, and Virginia due to constraints on the Columbia, Dominion, Eastern Shore, and Transco pipelines (Note: "Affected generation" does not imply a risk to electric reliability.)
- **Coordination Challenges**: As the generation fleet in PJM is transformed from largely coal-fired to increasing amounts of natural gas-fired generation, the challenges related to gas-electric coordination will increase.
- **Nearby Plentiful Gas Resource**: However, PJM also has the advantage of being located on two of the largest shale reserves in the United States, Marcellus and Utica.
  - Due to the close proximity to the Marcellus and Utica shale plays, natural gas-fired generators in PJM enjoy access to some of the cheapest gas in the United States.
  - Gas generators in PJM also have less fuel supply risk due to pipeline capacity constraints compared to other regions of the United States, such as ISO-NE, due to proximity to the commodity.
  - During periods of high-winter peak demand, gas-fired generators compete with retail-heating demand from gas LDCs, and some pipelines in PJM run at or near 100% capacity which creates deliverability risks.
  - With the implementation of the capacity performance product in PJM's capacity market (referred to as the reliability-pricing model or RPM), which includes stiff penalties for generators unable to meet their commitments when called upon, there is increasing evidence that generators in PJM have been firming up their fuel supply contracts.

PJM Footprint and Shale Gas Plays



Source: PJM

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



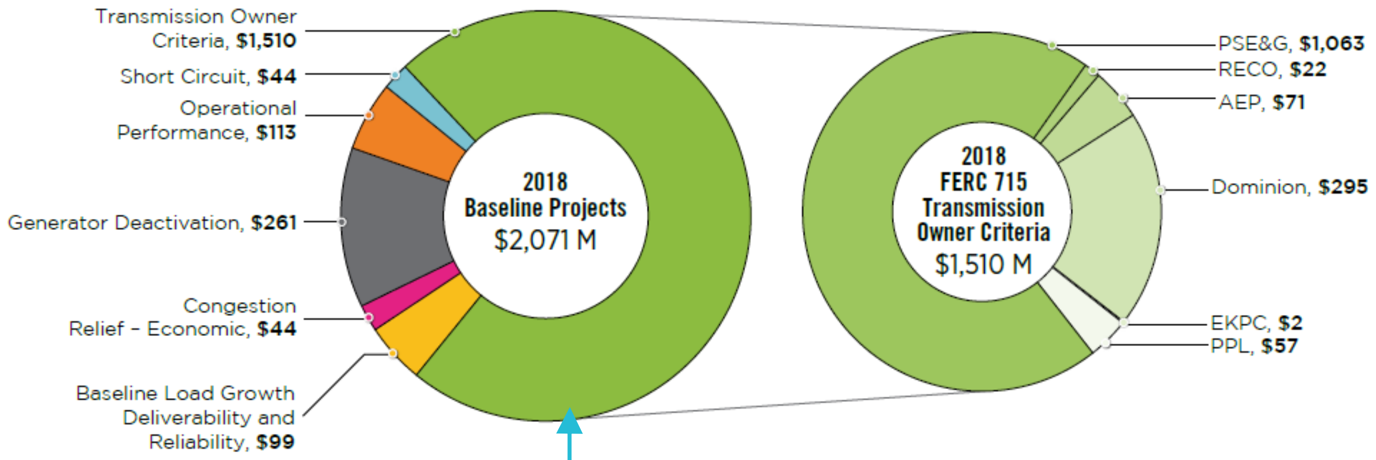
Sources: EIPC Study; NERC SPOD; PJM Resource Mix White Paper; 2018 Fuel Security Analysis

Resilience Issues (Cont'd)

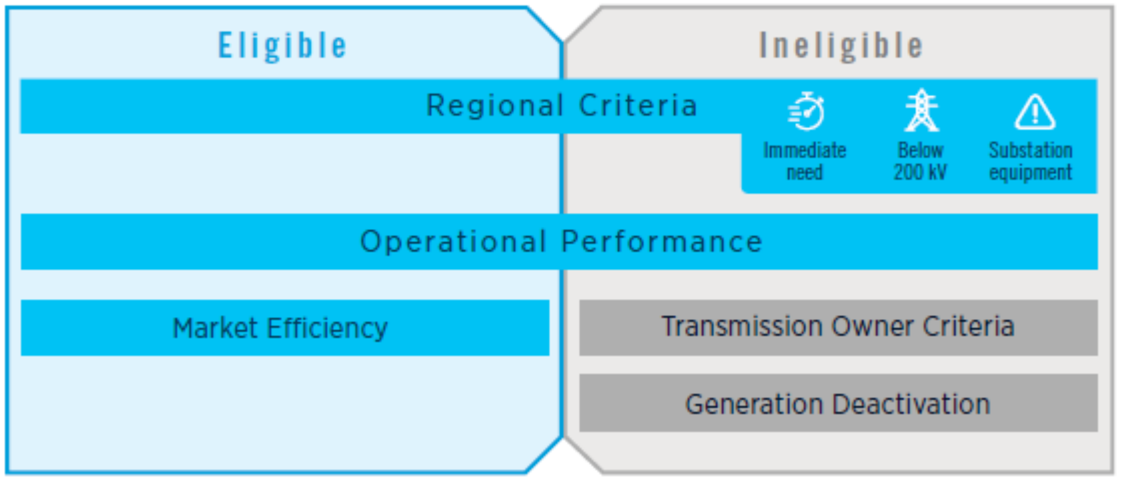
Aging Infrastructure

- PJM has observed that transmission owner aging infrastructure criteria are increasingly driving the need for baseline projects, and a review of facilities built in the 1960s and earlier has revealed deteriorating facilities.
- As depicted at right, the majority of baseline transmission projects included in the latest RTEP are driven by local transmission owner criteria, some to address aging infrastructure, others to address local loss-of-load thresholds (particularly on radial facilities).
- As outlined below, PJM assigns projects that are driven by local transmission owner criteria to the incumbent transmission owner, and those projects are not eligible for proposal window consideration.

2018 RTEP Baseline Projects by Driver



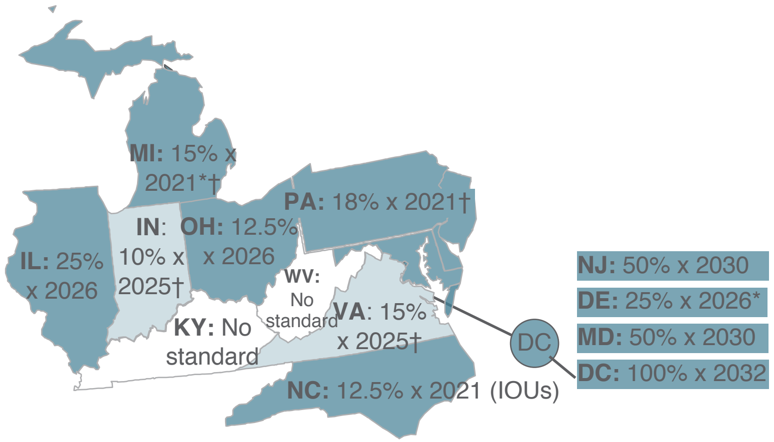
Proposal Window Eligibility by Project Driver



Sources: Benefits White Paper; 2018 RTEP

Renewables Integration

PJM State Renewable Portfolio Standards and Goals (as of June 2019)



Source: DSIREUSA.org, June 2019

- Renewable portfolio standard
- Renewable portfolio goal
- *Clean energy standard*
- *Clean energy goal*
- * Extra credit for solar or customer-sited renewables
- † Includes non-renewable alternative resources

Demand-Side Considerations

- **Low-Load Growth**: Overall demand growth in the region is expected to be less than 1% annually through 2028, although some metro areas across PJM are experiencing higher growth than rural areas. Energy efficiency and controllable, dispatchable demand response programs in the region are substantial in the summer (about 9.1 GWs or 6% of peak load) but less so in the winter (1.3 GWs or 1% of peak load). PJM also estimates that 4.5 GWs of distributed solar generation are present on the grid behind the meter.
- **Renewable Policy Differences**: PJM has a mix of states with moderate clean energy goals and standards, states with no standards at all, and the District of Columbia (see map at left). Washington D.C. has a 100% target by 2032. New Jersey and Maryland have 50% targets, whereas Kentucky and West Virginia do not have standards or targets in place.
- **Utility and Corporate Goals**: Some utilities in states touched by PJM'S footprint have also introduced clean and renewable energy commitments (see next page). PJM also notes that corporate and voluntary purchases of renewable energy are becoming an increasingly significant driver for renewable energy development in the region.
- **Policy Support for Some Generation**: In an attempt to strike a balance among the competing desires of states to subsidize certain resources and resource types (including renewable resources and also nuclear and coal resources in different cases) with the directives of the market, PJM recently proposed a revision to its capacity market rules.
  - However, FERC, in June 2018, determined that PJM's proposed capacity market rules were unjust and unreasonable because they failed to protect the market from the price-suppressive impacts of out-of-market support being provided by states to certain resources, such as renewable and nuclear generation.
  - The same order rejected two options that PJM asked FERC to choose between for fixing the problem. Instead, FERC floated its own proposed solution to ensure the rates produced by PJM's capacity auctions are just and reasonable, referred to as a replacement rate. It also instituted a paper hearing to determine the appropriate way to move ahead. A final decision from FERC is forthcoming.

Sources: NERC 2018 LTRA; DSIRE; SEPA; S&P Global Market Intelligence

Renewables Integration (Cont'd)

Listing of Utility Companies with Operations in PJM That Have Announced Emission Reductions or Renewable Energy Goals (as of September 2019)

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/Renewables	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)
Commonwealth Edison	Renewables	2025	25% renewables by 2025
Consumers Energy	Emission Reduction	2040	80% emissions reduction by 2040 (2018)
Dominion Energy	Emission Reduction	2030	60% reduction of carbon emissions from 2000 levels by 2030; 50% reduction in methane emissions from 2010 levels by 2030
DTE Energy	Emission Reduction	2040	80% emissions reduction by 2040 (2019)
Duke Energy	Emission Reduction	2032	40% reduction in carbon emissions from 2005 levels by 2032. 45% reduction in carbon intensity from 2005 levels
FirstEnergy	Emission Reduction	2045	90% reduction in CO_2 emissions from 2005 levels by 2045
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)
Public Service Enterprise Group	Emission Reduction	2050	80% reduction in carbon emissions by 2046, and net-zero carbon emissions by 2050
Tennessee Valley Authority	Emission Reduction	2020	60% reduction in CO_2 emissions from 2005 levels and 55% carbon-free power supply by 2020
Vectren Corp	Emission Reduction	2023	60% emissions reduction by 2023 (2018)

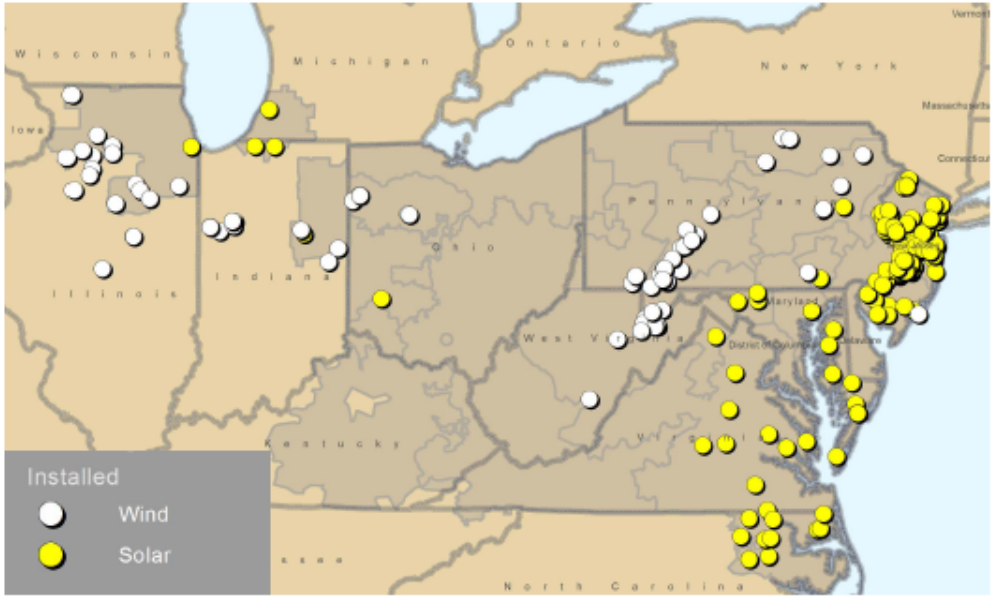
Sources: SEPA; S&P Global Market Intelligence

Renewables Integration (Cont’d)

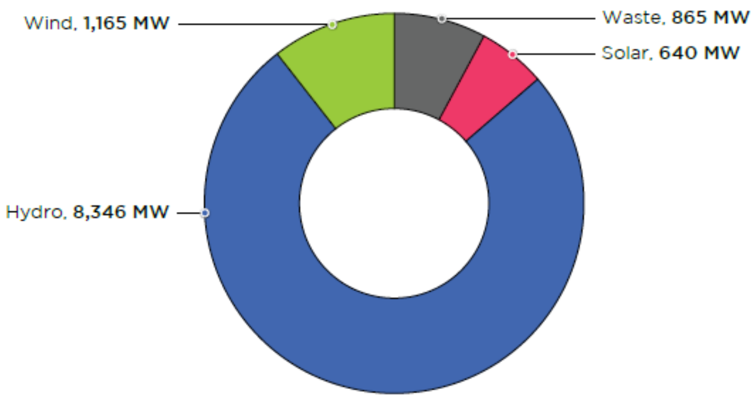
Supply-Side Considerations: Existing and Planned Renewables

- **Nearly 6 GWs Added**: Between 2011 and 2018, 5,910 MWs of wind and solar energy were interconnected to the PJM transmission grid to reach consumers across the region. The figure at top right shows the breakdown of existing renewable generation capacity by fuel.
- **Resource Location**: The majority of the wind capacity is located in the central and western portions of the PJM footprint, while most of the installed solar capacity is located in the east.
- **Solar Growing**: While wind capacity today is almost double the solar capacity in the region, the majority of the capacity in the queue is solar (see bottom right).

Installed Wind- and Solar-Powered Generation in PJM (As of 12/31/18)

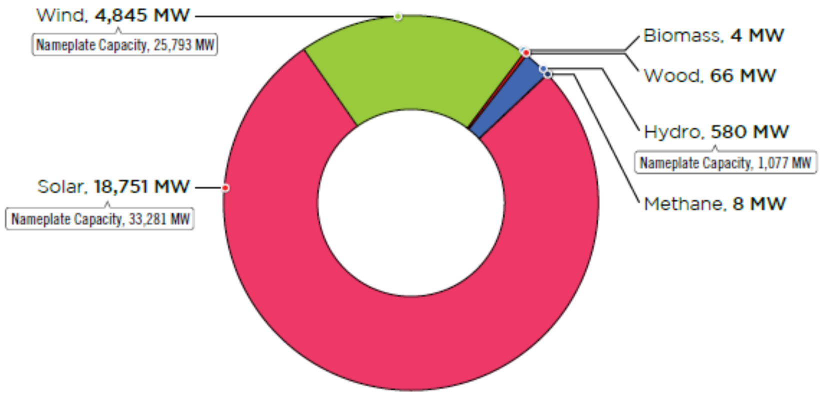


Existing Renewable Capacity in PJM (As of 12/31/18)



The majority of existing renewable capacity in PJM is hydro.

Queued Renewable Capacity in PJM (As of 12/31/18)



The majority of the interconnection queue is comprised of solar.

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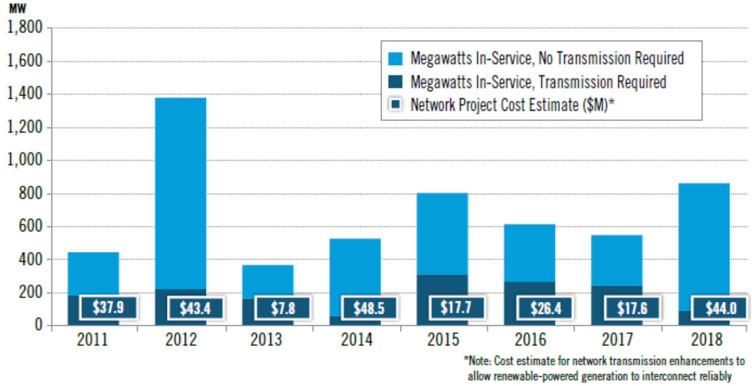
Sources: Benefits White Paper; 2018 RTEP

Renewables Integration (Cont'd)

Supply-Side Considerations: System Capacity to Accommodate Renewables

- PJM has produced a series of papers examining how aspects of its operations, planning, and markets could and should evolve given the changing landscape of the electric power industry.
- **Up to 30%**: First, PJM commissioned a study in 2011 to analyze the impacts to grid operations if renewable energy goals over the next 15 years are achieved or exceeded. Scenarios of up to 30% penetration of various combinations of variable wind and solar were analyzed, and the study found that the PJM system, with adequate transmission expansion and additional regulating reserves, will not have any significant issues operating with up to 30% of its energy provided by wind and solar generation (emphasis added).
- **2017 Study**: PJM conducted a follow-up study and issued a report in 2017 called "PJM's Evolving Resource Mix and Reliability," which was initiated by questions about "fuel diversity" that evaluated the changing resource mix in PJM given environmental regulations, the preponderance of low-cost natural gas, the increasing penetration of renewable resources and demand response, and the potential for retirements of nuclear power resources. Select findings included:
  - *Mixed Effects*: As the potential future resource mix moves in the direction of less coal and nuclear generation, generator reliability attributes of frequency response, reactive capability, and fuel assurance decrease, but flexibility and ramping attributes increase.
  - *Operational Reliability Issues*: A marked decrease in operational reliability for portfolios with significantly increased amounts of wind and solar capacity (compared to expected near-term portfolio) suggests performance-based upper bounds on the percent of system capacity from those resource types. Additionally, most portfolios with solar capacity shares of 20% or higher were classified infeasible because they resulted in violations at night. Nevertheless, PJM could maintain reliability with unprecedented levels of wind and solar resources, assuming a portfolio of other resources that provides a sufficient amount of reliability services.
  - *High Gas-Fired Generator Penetration*: Portfolios composed of up to 86% natural gas-fired resources maintained operational reliability. Thus, this analysis did not identify an upper bound for natural gas. However, additional risks, such as gas deliverability during polar vortex-type conditions and uncertainties, were not fully captured in the analysis.

Network Transmission Enhancements for New Generation – Renewable Fuels



While additional transmission investment may be needed to support the integration of renewables in PJM, other factors such as negative load growth, reduced congestion, and preference for for in-state renewables may temper future transmission needs.

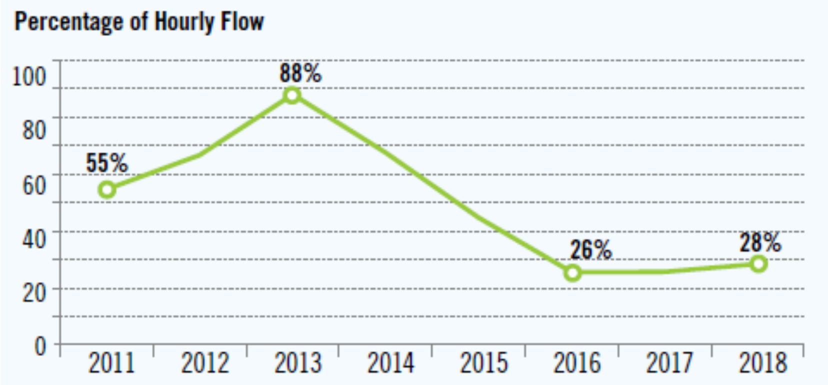
Source: PJM Resource Mix White Paper

Renewables Integration (Cont’d)

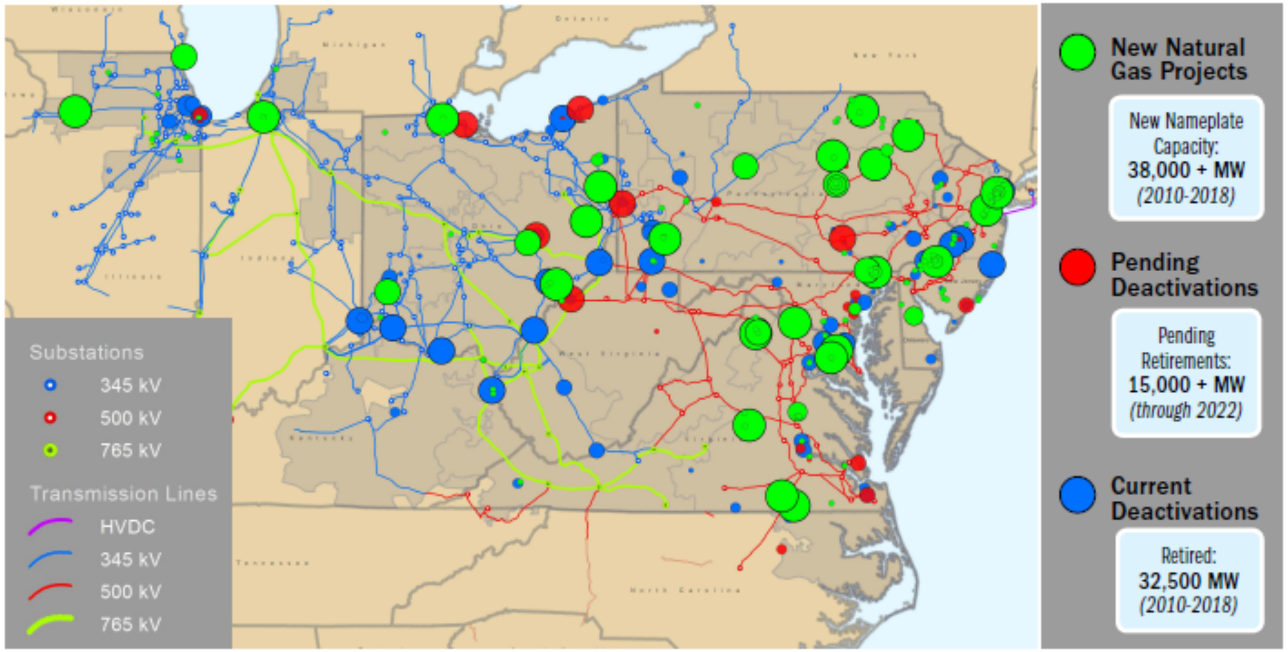
Supply-Side Considerations: Changing Power Flows

- **Historically West-to-East**: Historically, power flow across PJM transmission lines has moved from west to east. High-voltage transmission assets were approved to deliver lower-priced western PJM coal-fired generation reliably to eastern PJM load centers, but that power flow is moderating.
- **Flows Declining**: The combination of generation retirements across the PJM footprint coupled with the increase of natural gas generation in the east is driving a shift on some transfer interfaces, as shown below. PJM has observed reduced west-to-east power flows.

Average Hourly West-to-East Power Flow at the Central Interface



Generation Capacity Entry and Exit Since 2010

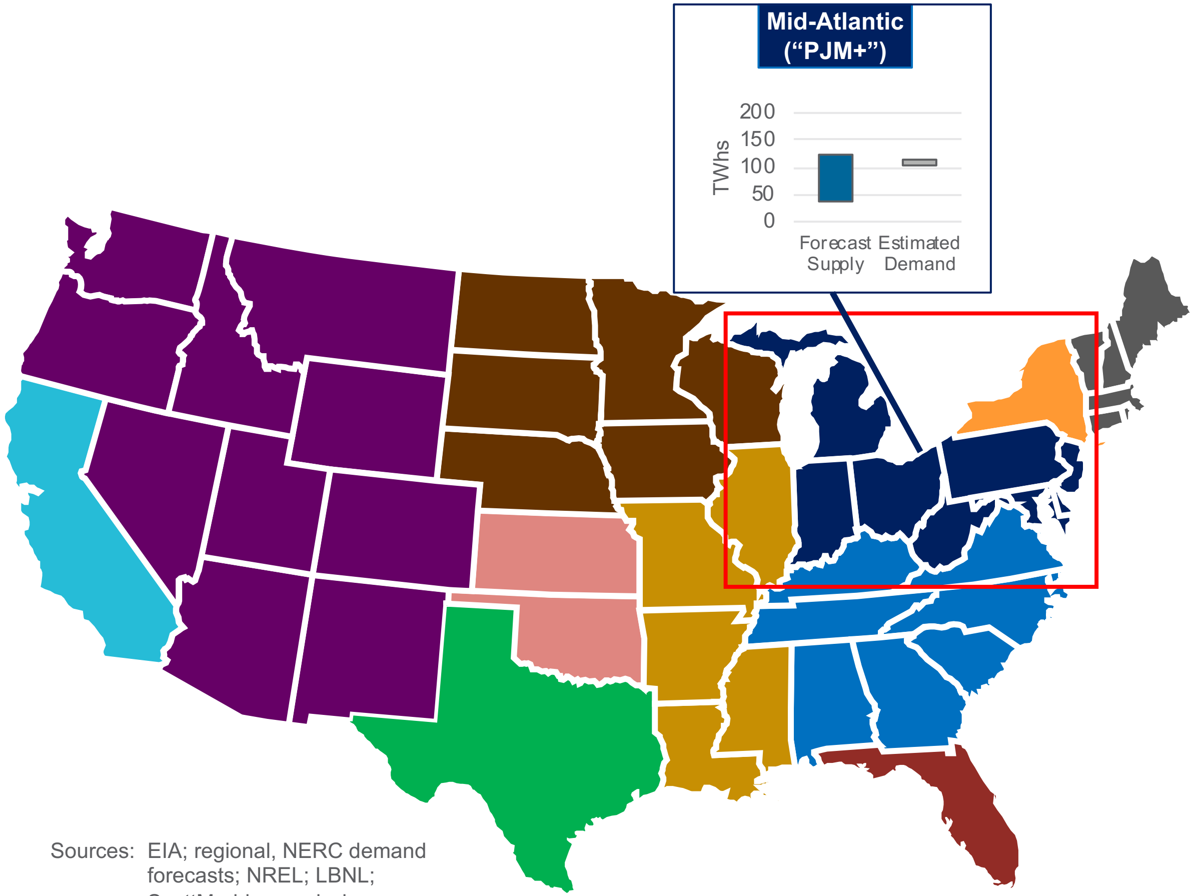


PJM credits the operational flexibility of its transmission assets for encouraging new generation within PJM’s footprint, particularly natural gas-fired generation using Marcellus and Utica shale gas. In other words, transmission assets are accommodating a historic fuel shift, while keeping the system reliable. Transmission is assisting this shift by allowing more generators to compete so that the lowest-cost generation serves customer load throughout the footprint.

Sources: Benefits White Paper; 2018 RTEP

Renewables Integration (Cont'd)

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

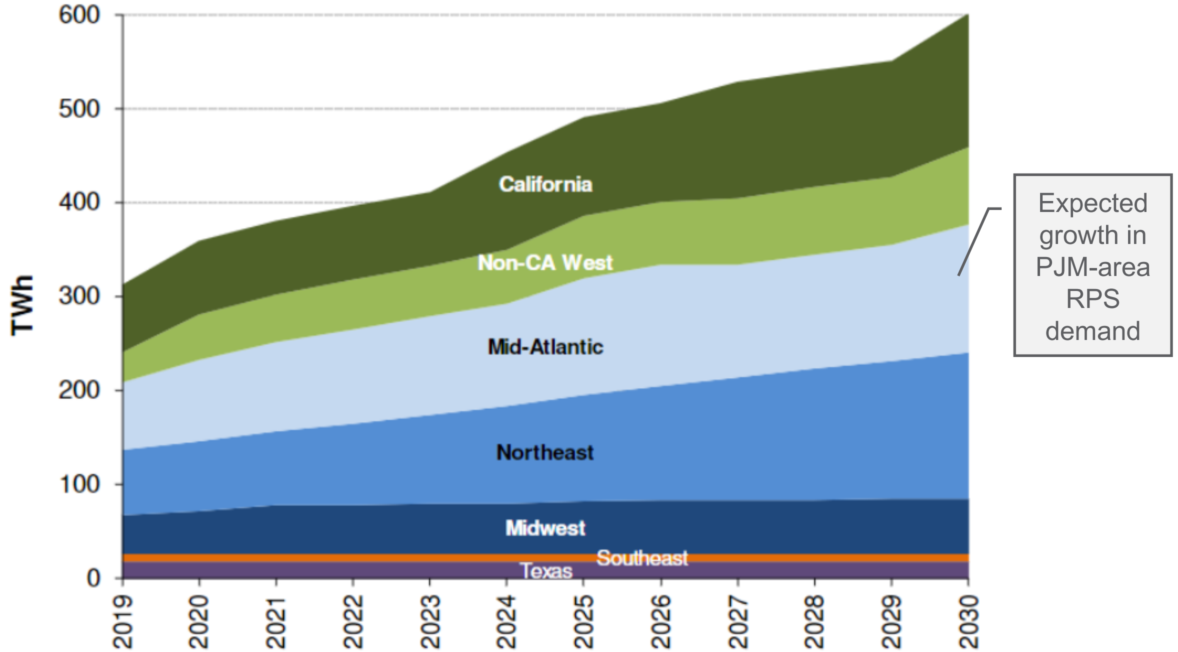


Sources: EIA; regional, NERC demand forecasts; NREL; LBNL; ScottMadden analysis

Integration Challenges – Renewables Supply and Demand Balance

- As seen in the map at left and the Mid-Atlantic section of the chart below, the estimated demand for renewable resources in the PJM region is expected to be at the high end of the range of forecasted supply of renewables in the region, suggesting that much of the demand may be met by resources inside the PJM region.

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



Source: LBNL

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

Implications for Transmission

	Resilience	Integration of Renewables	Other Factors	Transmission Opportunities
PJM Interconnection	▪ Resource portfolio "transformation" to gas-fired and intermittent resources—deactivation of 27 GWs of coal from 2011 to 2020, including 12 GWs submitted to PJM in 2018, with 50.6 GWs of gas generation in the queue ▪ Exposure to system stress during sustained heat waves and cold snaps ▪ Severe weather greatest cause of electric disturbances: tropical cyclones and severe winter weather ▪ Ongoing resilience initiatives related to spare transformers, deployment of PMUs, and modeling-simulated severe contingency events	▪ Hydropower represents 4.5% of total market-eligible existing installed capacity in PJM, and wind, solar, and waste each represent less than 1% ▪ Current queue includes 18,751 MWs of solar and 4,845 MWs of wind, representing 33,281 MWs and 25,793 MWs of nameplate capacity, respectively ▪ The highest quality wind resources are located in the western portion of the footprint ▪ New but growing deployment of distributed solar in some areas	▪ Widely varying state policies related to renewable energy; aggressive clean energy goals in DC, NJ, and MD; moderate or no goals in other states ▪ Disparate clean energy goals among the states within the region has led to a contentious capacity market ruling by Federal Energy Regulatory Commission (FERC), issued in December 2019 and likely to generate more debate when PJM makes it compliance filing. ▪ Long on gas generation capacity, with expected additional capacity developed due to proximity to shale gas plays ▪ Congestion considered to be minor in most areas, and mitigation by additional transmission upgrades is not currently warranted; uplift and congestion charges have been low since 2011 ▪ Low to negative load growth expectation in the region for the planning horizon	▪ $37.1B invested in transmission since 1999, including $2.1B new baseline projects and $1B in new network projects approved in the 2018 RTEP ▪ Continued opportunity for transmission owners to replace and upgrade aging assets via supplemental projects, most of which are driven by material condition, performance, and risk ▪ Opportunity to address remaining load pockets in certain areas on the East Coast ▪ Potential to connect and integrate offshore wind under consideration and in development in the Atlantic ▪ "Gas-by-wire" could provide opportunities to meet demands in neighboring regions with cheap gas-fired power generated closer to shale gas sources

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- S&P Global Market Intelligence

Appendix: Transmission Project Selection Criteria

Planning Process

- RTEP identifies system upgrades and enhancements to meet planning and reliability criteria over a 15-year time horizon

Project Identification

- PJM calculates a benefit/cost ratio to determine if there is a market efficiency justification for a particular transmission enhancement. The benefit/cost ratio is calculated by comparing the net present value of annual benefits over the first 15 years of the project's life to the net present value of the project's revenue requirement for the same period. Market efficiency proposed transmission enhancements that meet or exceed a 1.25 benefit/cost ratio are further assessed to examine their economic, system reliability, and constructability impacts

Criteria for Competitive Projects

- Long-lead reliability projects (needed in five+ years)
- Short-term reliability projects (needed in four to five years)
- Immediate need reliability projects (needed in two years or less) may or may not be eligible for competition
- Market-efficiency projects

Evaluation Criteria

- Short-term project or long-lead project must address and solve the posted violation, system condition, or economic constraint
- Must meet a benefit/cost ratio threshold of at least 1.25:1
- Secondary benefits (additional reliability, operational, economic, and public policy benefits)

Sources: PJM, Order 1000 Compliance Filing with FERC