



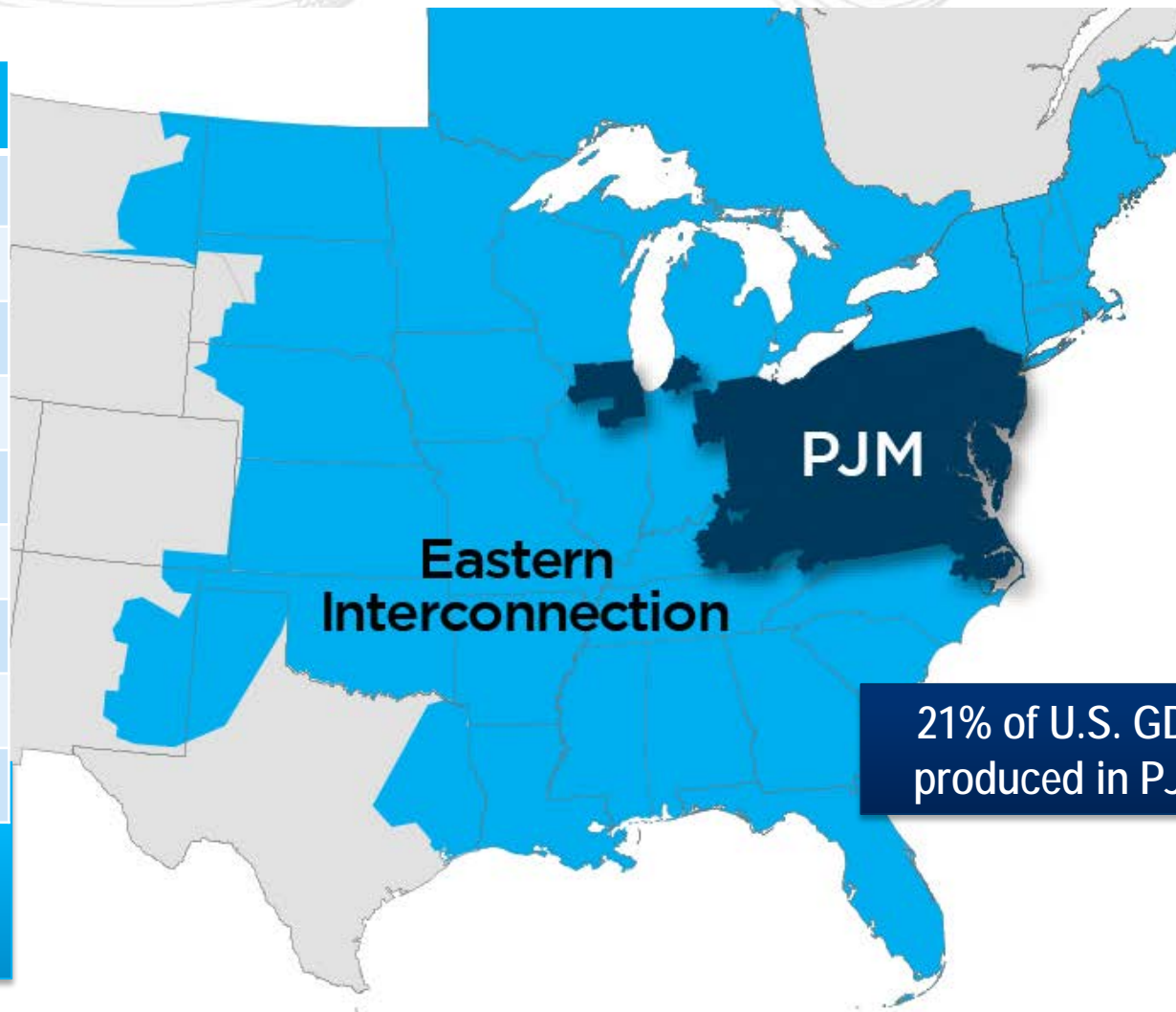
Integrating Renewables in PJM

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PJM Interconnection
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Key Statistics

Member companies	1,040+
Millions of people served	65
Peak load in megawatts	165,492
MW of generating capacity	178,563
Miles of transmission lines	84,042
2017 GWh of annual energy	773,522
Generation sources	1,379
Square miles of territory	243,417
States served	13 + DC

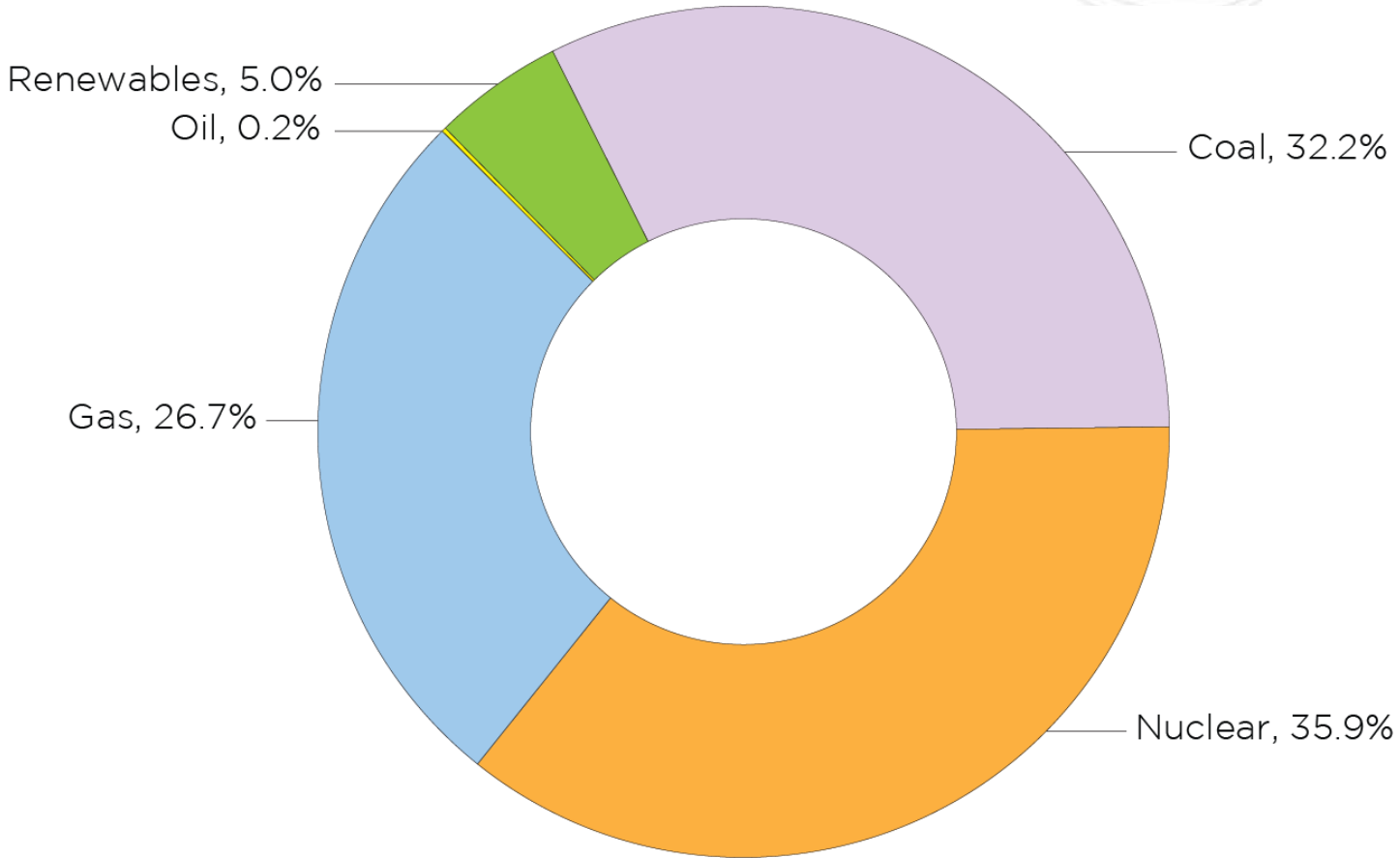
- 28% of load in Eastern Interconnection
- 20% of transmission assets in Eastern Interconnection



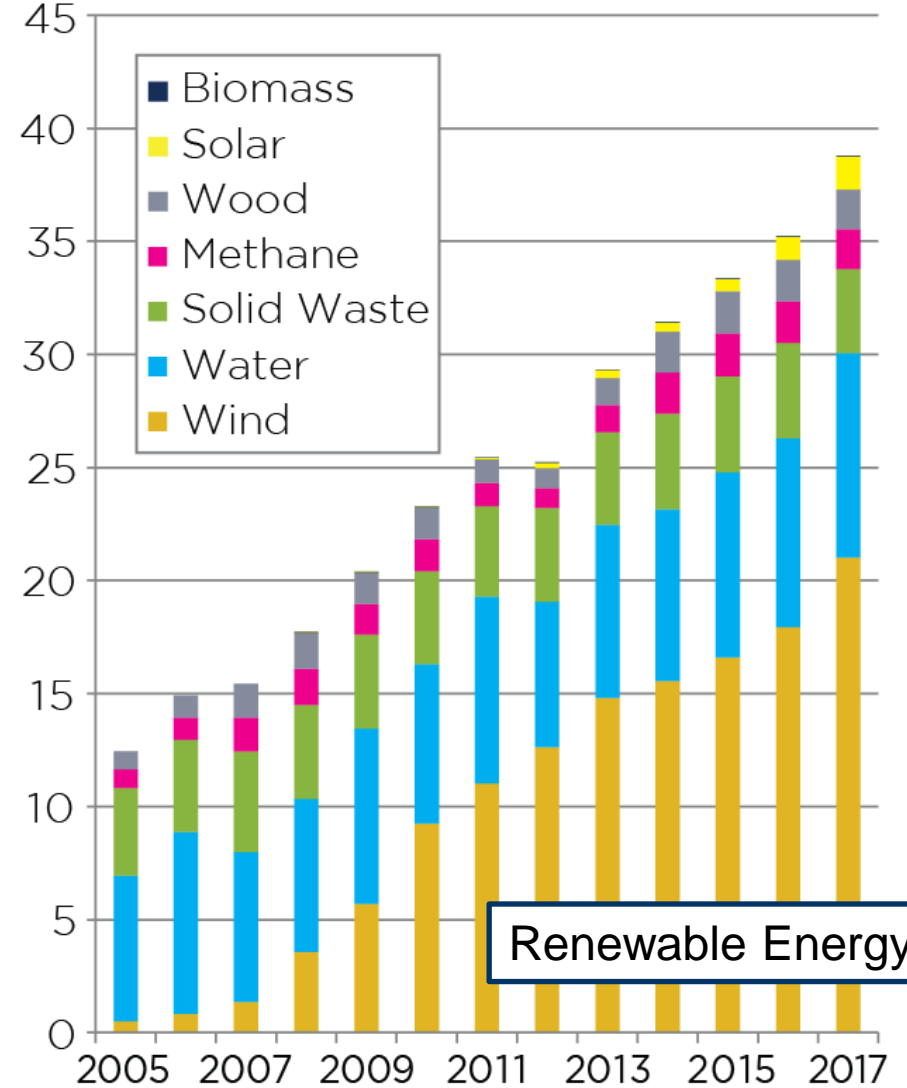
As of 2/2018

Percentage of Renewable Energy is Small but Growing

PJM Generation Mix – 2017 Annual Energy



MWh (millions)



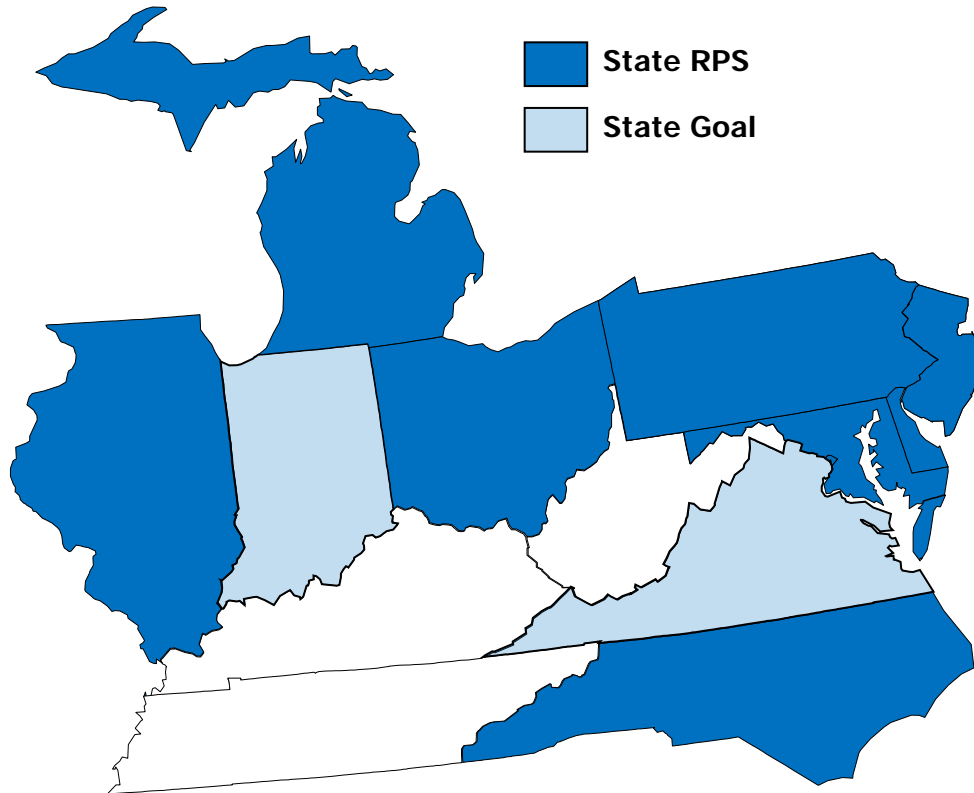
State Renewable Portfolio Standards (RPS) require suppliers to utilize wind and other renewable resources to serve an increasing percentage of total demand.

State RPS Targets

- ☀ NJ: 20.38% by 2021
- ☀ MD: 25% by 2020
- ☀ DE: 25% by 2026
- ☀ DC: 50% by 2032
- ☀ PA: 18%** by 2021
- ☀ IL: 25% by 2026
- ☀ OH: 12.5% by 2026
- ☀ NC: 12.5% by 2021 (IOUs)
- MI: 15% by 2021
- VA: 15% by 2025
- IN: 10%** by 2025

☀ Minimum solar requirement

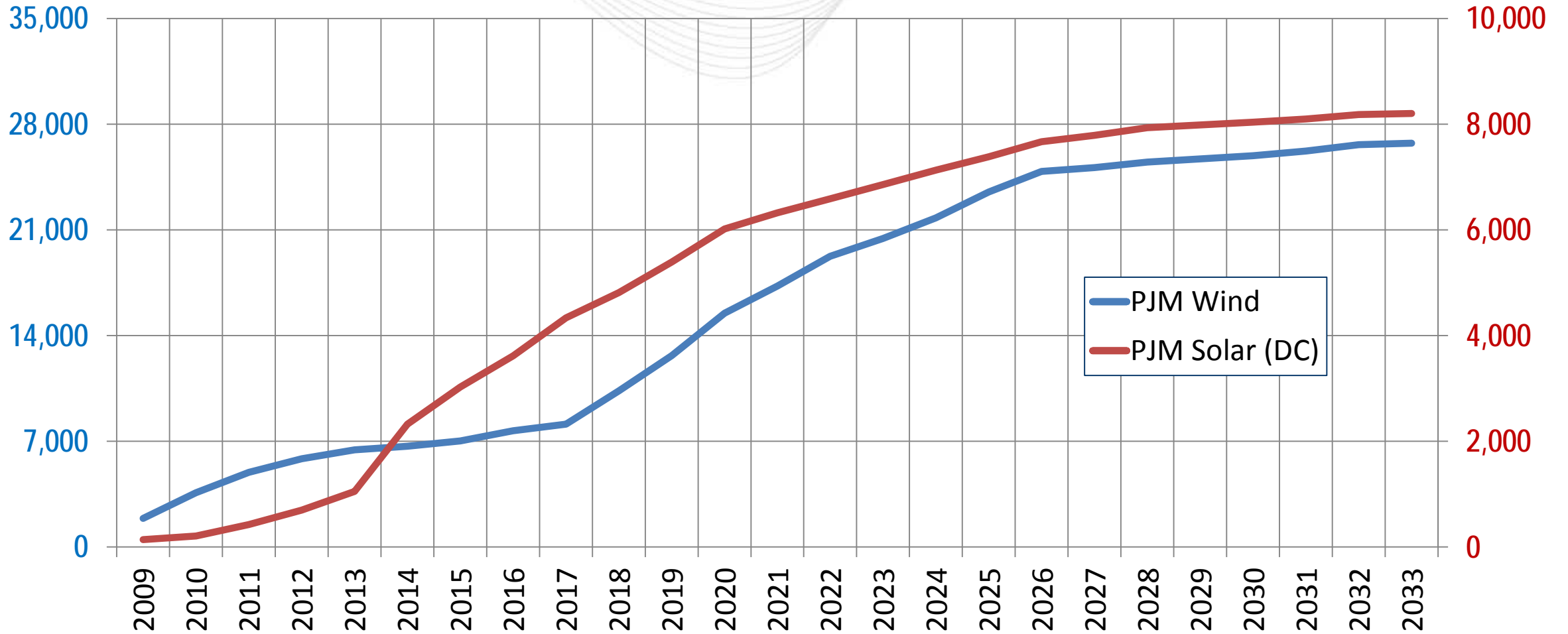
** Includes non-renewable "alternative" energy resources



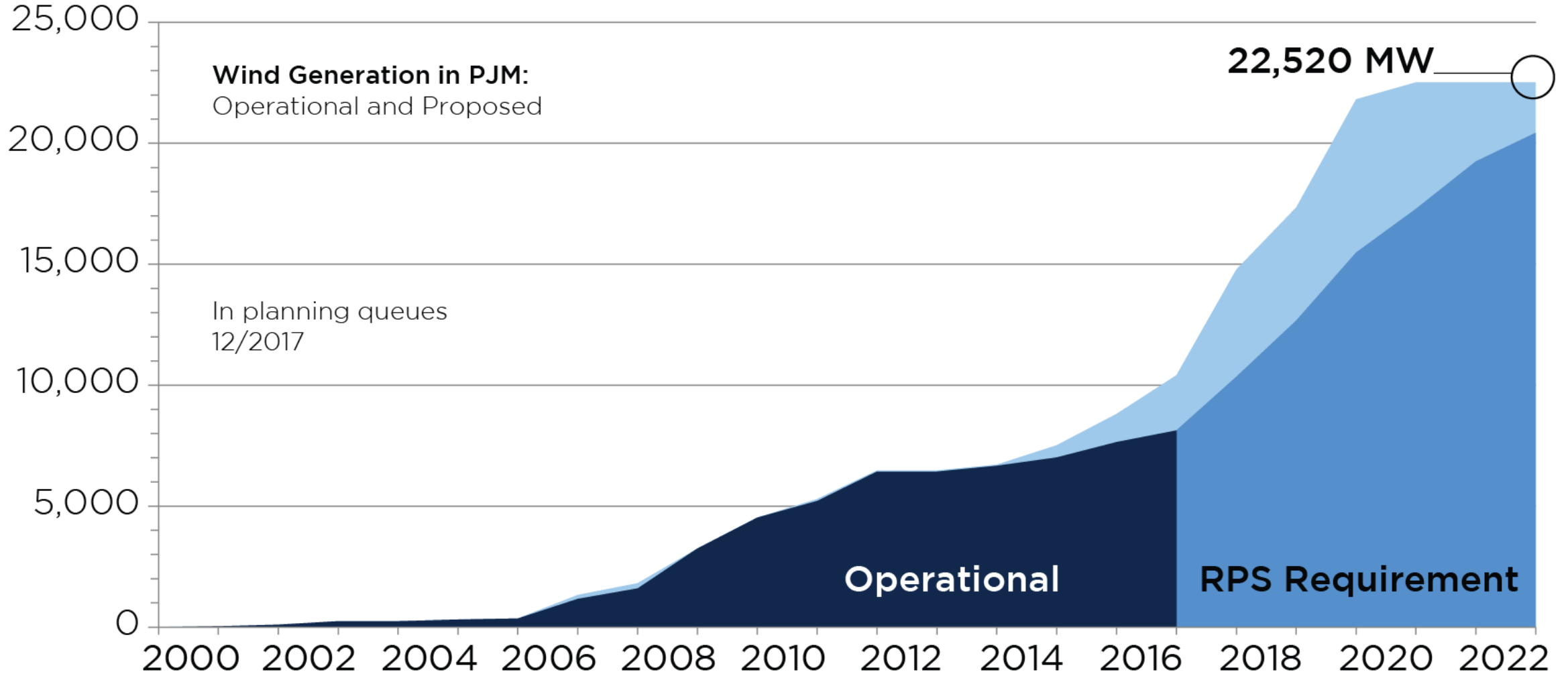


Projected Renewable Energy Requirements

117 TWhs of Energy (13.5% of PJM load) by 2033; **27 GW** of Wind, **8 GW** of Solar



Cumulative Nameplate (MW)





Impact of Increasing VER Penetration

Regional markets reduce Variable Energy Resource integration costs

Characteristic	Impact to Integration Cost
Larger balancing areas	<ul style="list-style-type: none">• Reduces overall increase in variability• Less regulation and ramping service required
Faster markets, i.e., shorter scheduling intervals (5-15 minutes)	<ul style="list-style-type: none">• Less regulation required to accommodate intra-hour variations
Larger geographic area	<ul style="list-style-type: none">• Increases weather diversity and reduces overall variability
Centralized wind and solar power forecasting	<ul style="list-style-type: none">• Cost-effective approach to reduce scheduling impacts
Regional / Interregional Transmission Planning	<ul style="list-style-type: none">• Cost-effective upgrades to ensure grid reliability and mitigate congestion

Energy Markets / Operations

- Implemented a centralized wind power forecast service
- Solar power forecast is in progress
- Implemented changes to improve wind resource dispatch / control
- Demand Response / Price Responsive Demand improves operational flexibility
- Frequency Regulation – “pay for performance” rewards better performing resources (like storage)
- Interchange Scheduling – compliant with FERC Order 764 (15-minute intervals)

Transmission Planning

- Light load criteria implemented to improve grid reliability
- Expansion planning considers public policy impacts (i.e., RPS)
- Grid interconnection – enhanced standards for new inverter-based resources (wind and solar)



Evaluating Potential Grid Impacts

- PJM Renewable Integration Study (PRIS) - assessed grid impacts

Advanced Technology Research Program (ATRP)

- Pilot programs to evaluate new technologies and remove barriers to participation in PJM markets and operations.

- GE Energy Consulting – overall project leadership, production cost and capacity value analysis
- AWS Truepower – development of wind and solar power profile data
- EnerNex – statistical analysis of wind and solar power, reserve requirement analysis
- Exeter Associates – review of industry practice/experience with integration of wind/solar resources
- Intertek Asset Integrity Management (Intertek AIM), formerly APTECH – impacts of increased cycling on thermal plant O&M costs and emissions
- PowerGEM – transmission expansion analysis, simulation of sub-hourly operations and real-time market performance



- Contract was executed on May 17, 2011.
- Final study results were reviewed with stakeholders on March 3, 2014.

ID	Task Name	Start	Finish	Duration	Q2 11		Q3 11			Q4 11			Q1 12			Q2 12			Q3 12			Q4 12			Q1 13			Q2 13			Q3 13			Q4 13		
					May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Task 1: PRIS Wind and Solar Profile Development	5/17/2011	3/30/2012	229d	[Gantt bar from May 2011 to March 2012]																															
2	Task 2: Scenario Development and Analysis	5/17/2011	4/13/2012	239d	[Gantt bar from May 2011 to April 2012]																															
3	Task 3: Scenario Simulation and Analysis	4/16/2012	10/31/2013	404d	[Gantt bar from April 2012 to October 2013]																															
4	Literature Review	6/1/2012	10/31/2012	109d	[Gantt bar from June 2012 to October 2012]																															
5	Task 3A: Operational Analysis	4/16/2012	5/31/2013	295d	[Gantt bar from April 2012 to May 2013]																															
6	MAPS set-up, scenario simulations	4/16/2012	12/14/2012	175d	[Gantt bar from April 2012 to December 2012]																															
7	Task 3 Progress meeting at PJM	2/12/2013	2/12/2013	0d	[Milestone diamond at Feb 2013]																															
8	Draft Report: LOLE, Reserves, Transmission	12/17/2012	5/1/2013	98d	[Gantt bar from Dec 2012 to May 2013]																															
9	Draft Report: Production costs, PROBE, Cycling analysis	12/17/2012	5/31/2013	120d	[Gantt bar from Dec 2012 to May 2013]																															
10	Task 3B: Market Analysis	6/3/2013	10/31/2013	109d	[Gantt bar from June 2013 to October 2013]																															
11	Task 4: Mitigation, Facilitation and Report	11/1/2013	12/5/2013	25d	[Gantt bar from Nov 2013 to Dec 2013]																															
12	Milestone: Final Report Review Meeting	12/6/2013	12/6/2013	0d	[Milestone diamond at Dec 2013]																															

Scenario	Renewable Penetration in PJM	Wind/Solar (GWh)	Wind + Solar Siting	Years Simulated	Comments
2% BAU	Reference	Existing wind + solar	Existing Plants (Business as Usual)	3 years	Benchmark Case for Comparing Scenarios
14% RPS	Base Case 14%	109 / 11	Per PJM Queue & RPS Mandates	3 years	Siting based on PJM generation queue and existing state mandates
20% LOBO	20%	150 / 29	Low Offshore + Best Onshore	3 years	Onshore wind selected as best sites within all of PJM
20% LODO	20%	150 / 29	Low Offshore + Dispersed Onshore	1 year	Onshore wind selected as best sites by state or region
20% HOBO	20%	150 / 29	High Offshore + Best Onshore	1 year	High offshore wing with best onshore wind
20% HSBO	20%	121 / 58	High Solar + Best Onshore	1 year	High solar with best onshore wind
30% LOBO	30%	228 / 48	Low Offshore + Best Onshore	3 years	Onshore wind selected as best sites within all of PJM
30% LODO	30%	228 / 48	Low Offshore + Dispersed Onshore	1 year	Onshore wind selected as best sites by state or region
30% HOBO	30%	228 / 48	High Offshore + Best Onshore	1 year	High offshore wing with best onshore wind
30% HSBO	30%	179 / 97	High Solar + Best Onshore	1 year	High solar with best onshore wind

- The PJM system, with additional reserves and transmission build-out, could handle renewable penetration levels up to 30%.
- The principal impacts of higher penetration of renewable energy into the grid include:
 - Lower Coal and CCGT generation under all scenarios
 - Lower emissions of criteria pollutants and greenhouse gases
 - No loss of load and minimal renewable energy curtailment
 - Lower system-wide production costs
 - Lower generator gross revenues*
 - Lower average LMP and zonal prices

* Note: This study did not evaluate potential impacts on PJM Capacity Market results due to reduced generator revenues from the wholesale energy market, nor did it evaluate the impact of renewables to rate payers. It is conceivable that lower energy prices would be at least partially offset by higher capacity prices.

PJM Renewable Integration Study shows a need for regulation reserves to increase under all scenarios, especially under High Solar scenarios.

Regulation	Load Only	2% BAU	14% RPS	20% HOBO	20% LOBO	20% LODO	20% HSBO	30% HOBO	30% LOBO	30% LODO	30% HSBO
Maximum (MW)	2,003	2,018	2,351	2,507	2,721	2,591	2,984	3,044	3,552	3,191	4,111
Minimum (MW)	745	766	919	966	1,031	1,052	976	1,188	1,103	1,299	1,069
Average (MW)	1,204	1,222	1,566	1,715	1,894	1,784	1,958	2,169	2,504	2,286	2,737
% Increase Compared to Load		1.5%	30.1%	42.4%	57.3%	48.2%	62.6%	80.2%	108.0%	89.8%	127.4%



- **Adjustments to Regulation Requirements**
 - *Develop a method to determine regulation requirements based on forecasted levels of wind and solar production. Day-ahead and shorter term forecasts could be used for this purpose.*
- **Renewable Energy Capacity Valuation**
 - *Consider an annual or bi-annual application of ELCC methodology in order to calibrate PJM's renewable capacity valuation methodology in order to occasionally adjust the applicable capacity valuation of different classes of renewable energy resources in PJM.*
- **Mid-Term Commitment & Better Wind and Solar Forecast**
 - *Consider using a mid-range wind and solar forecast in real-time operations to update the commitment of intermediate units (such as combined cycle units that could start in a few hours). This would result in less reliance on higher cost peaking generation.*
- **Exploring Improvements to Ramp Rate Performance**
 - *Explore the reasons for ramping constraints on specific units, determine whether the limitations are technical, contractual, or otherwise, and investigate possible methods for improving ramp rate performance.*

- Flexible resources will be needed to offset the impacts of variable generating resources
- New market players:
 - Distributed Energy Resources
 - Smart Grid Technologies
 - Energy Storage Resources
- Potential market changes:
 - New tools to improve forecasting and scheduling capabilities
 - New market mechanisms to incent flexible resources
 - Synchronized and Operating Reserve Market Enhancements
 - Shortage Pricing
 - Fast Start Pricing

- **PJM Initiatives:**

- PJM Learning Center: Alternative & Renewable Generation
 - » <http://learn.pjm.com/energy-innovations/alternative-renewable-gen.aspx>
- PJM Renewable Integration Study (PRIS) Reports
 - » <http://www.pjm.com/committees-and-groups/subcommittees/irs/pris.aspx>

- **Other Publications:**

- Energy Systems Integration Group (EVIG)
 - » <https://www.esig.energy/resources/>
- National Renewable Energy Laboratory (NREL) Renewable Electricity Futures
 - » https://www.nrel.gov/analysis/re_futures/index.html