Integrating Renewables in PJM

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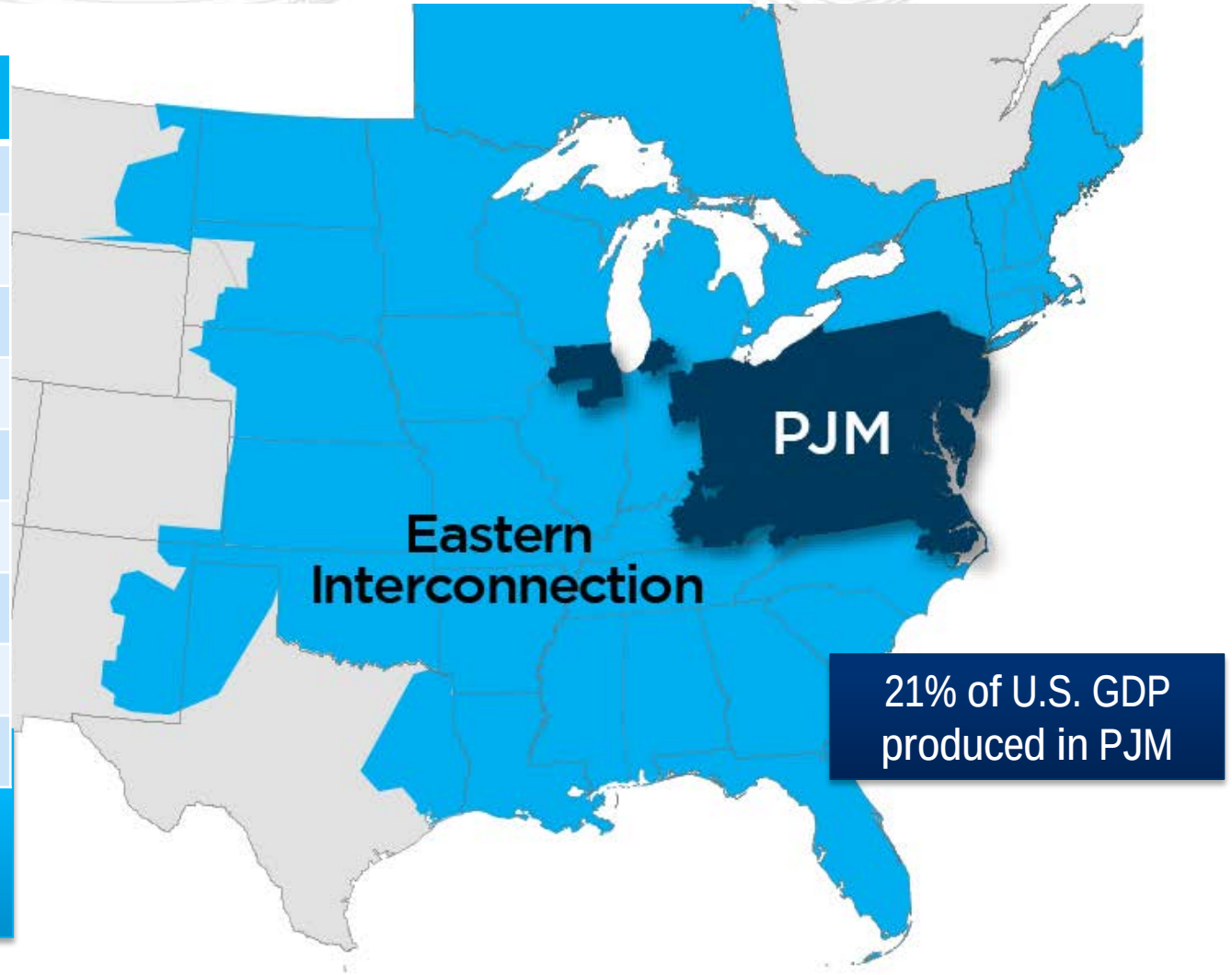
PJM as Part of the Eastern Interconnection

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

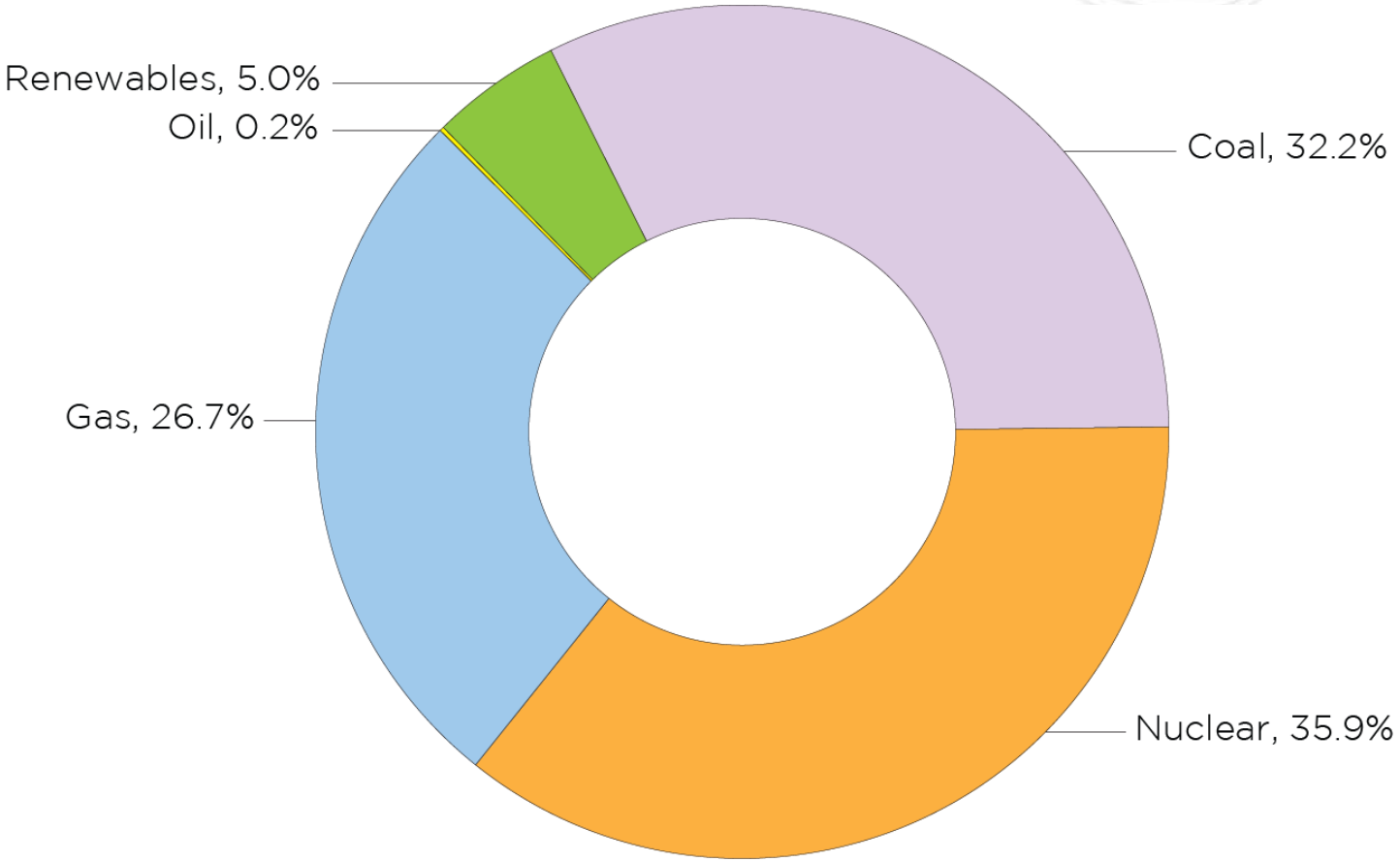
- 28% of load in Eastern Interconnection
- 20% of transmission assets in Eastern Interconnection

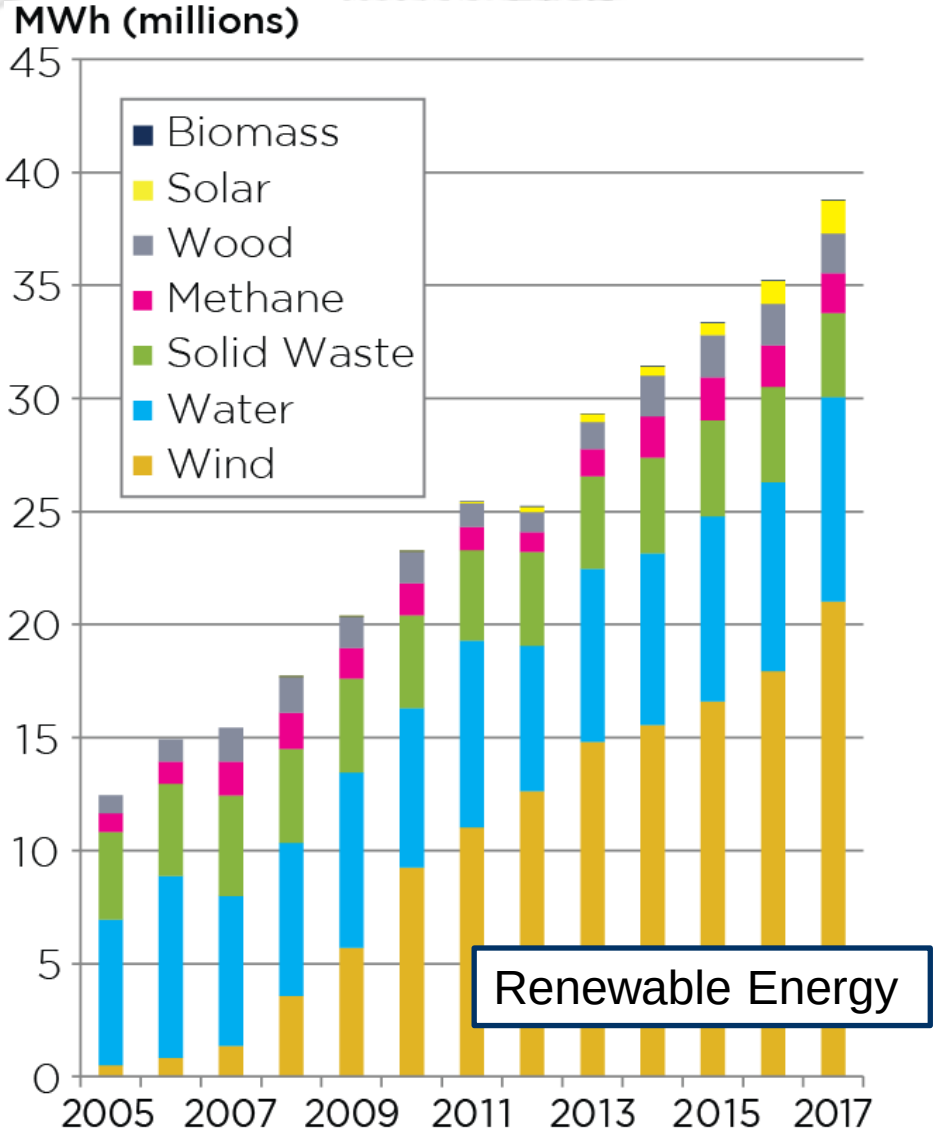


As of 2/2018

Percentage of Renewable Energy is Small but Growing

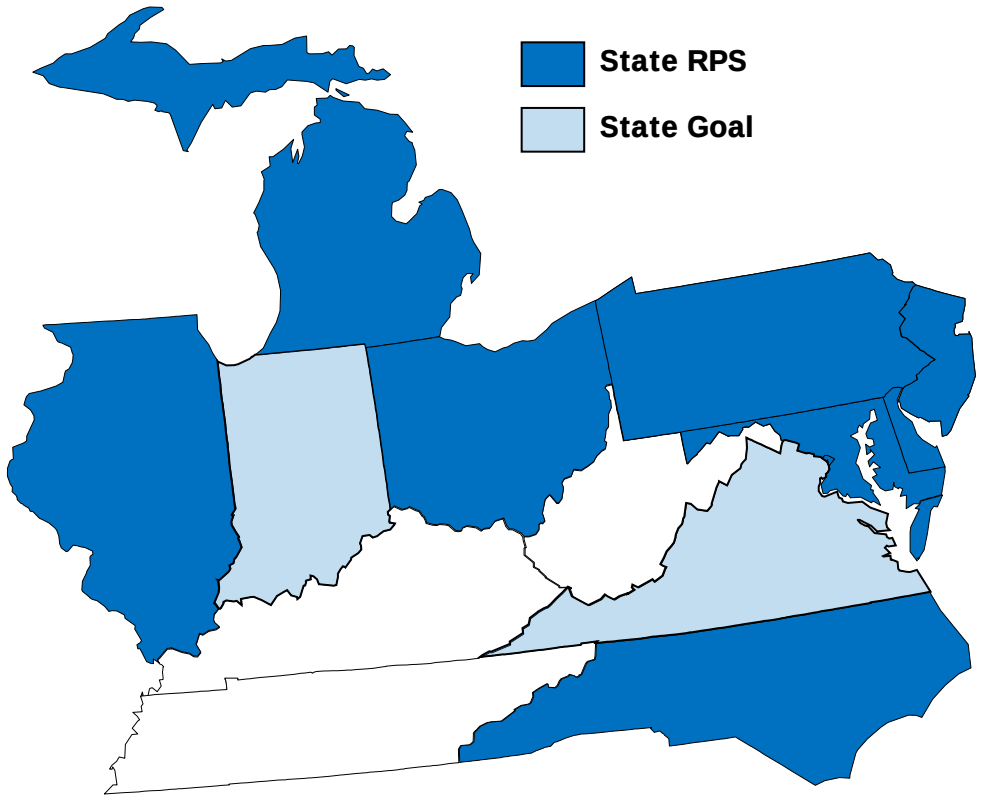
PJM Generation Mix – 2017
Annual Energy





PJM States with RPS

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



DSIRE: www.dsireusa.org February 2018

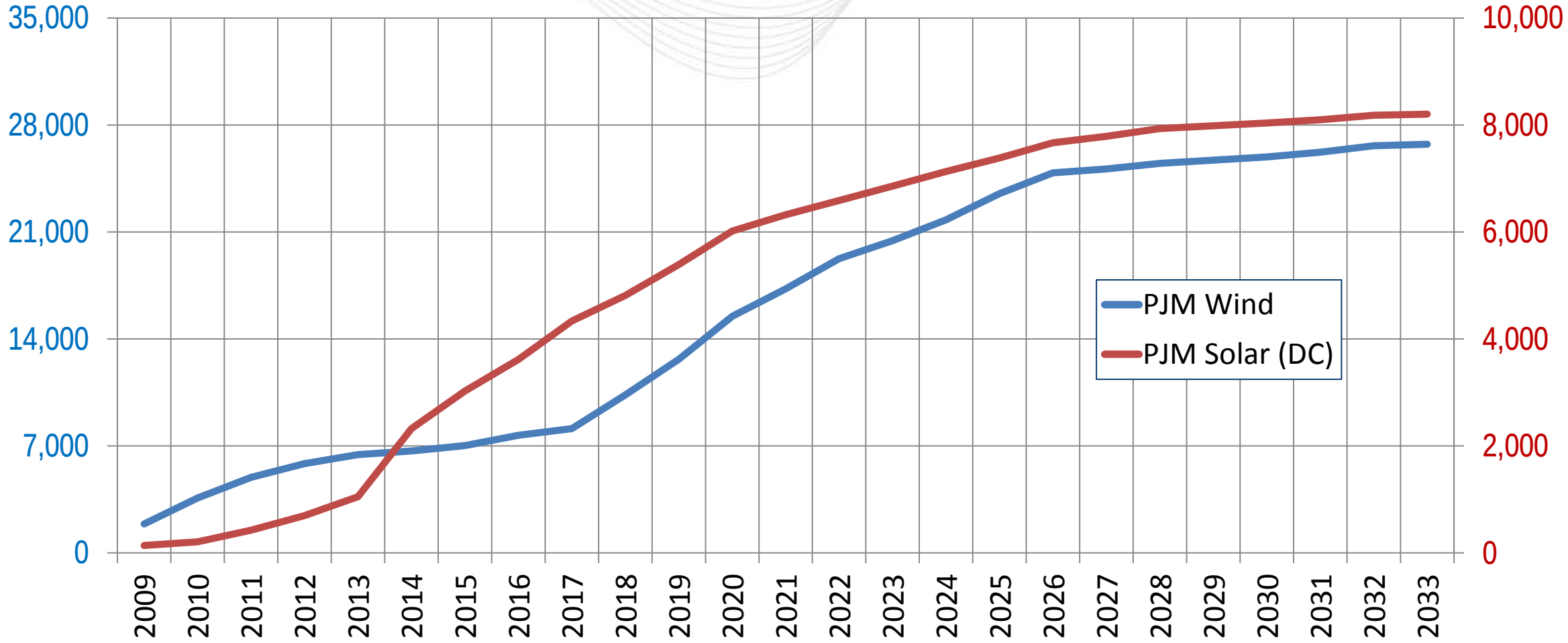
State RPS Targets

- ☼ 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

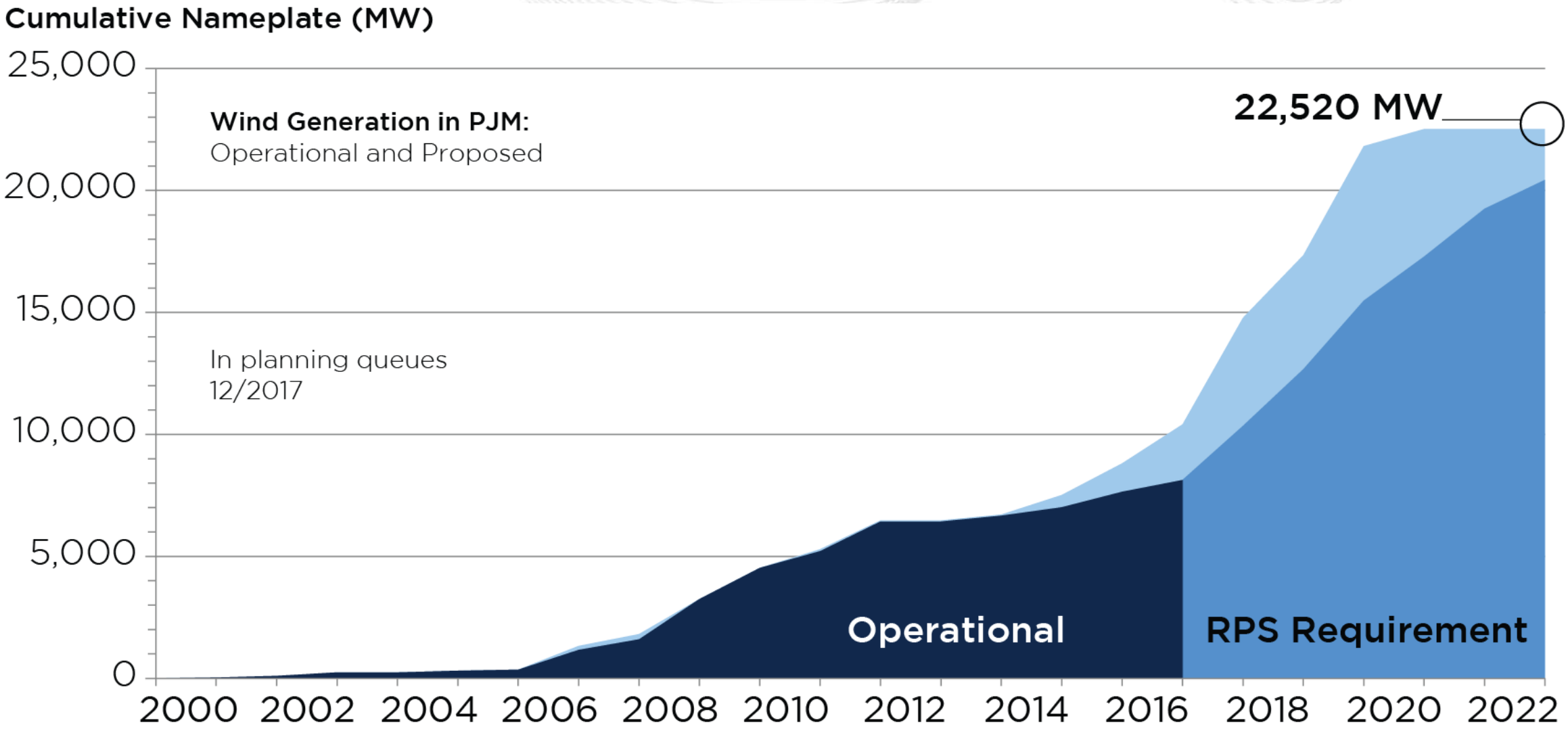
☼ Minimum solar requirement
** Includes non-renewable “alternative” energy resources

Projected Renewable Energy Requirements

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



2017 Wind Generation in PJM



Impact of Increasing VER Penetration

Regional markets reduce Variable Energy Resource integration costs

Characteristic	Impact to Integration Cost
Larger balancing areas	• Reduces overall increase in variability • Less regulation and ramping service required
Faster markets, i.e., shorter scheduling intervals (5-15 minutes)	• Less regulation required to accommodate intra-hour variations
Larger geographic area	• Increases weather diversity and reduces overall variability
Centralized wind and solar power forecasting	• Cost-effective approach to reduce scheduling impacts
Regional / Interregional Transmission Planning	• Cost-effective upgrades to ensure grid reliability and mitigate congestion

PJM Initiatives to Address Impacts

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.

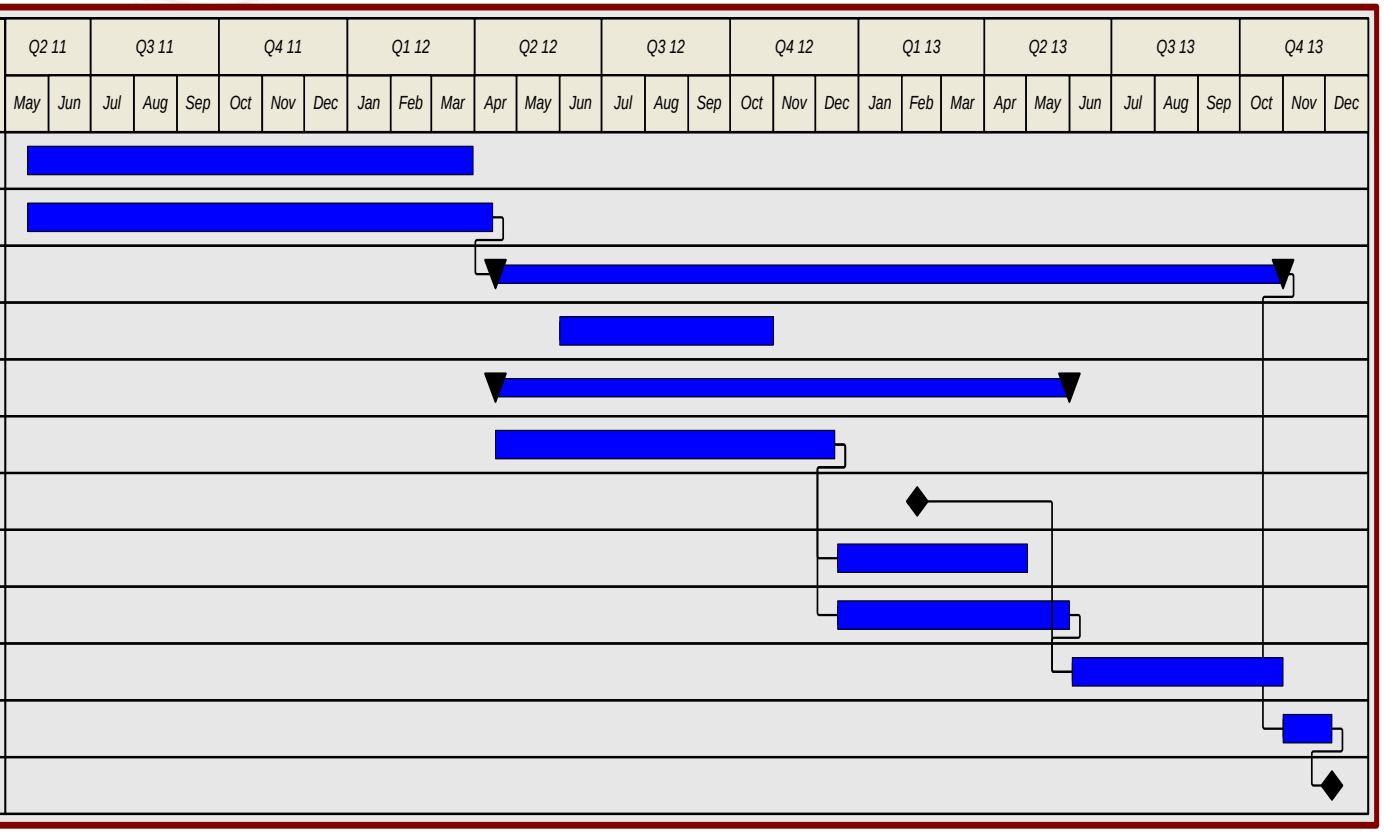
PJM Renewable Integration Study (PRIS) Project Team

- 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

PRIS Project Schedule

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

ID	Task Name	Start	Finish	Duration
1	Task 1: PRIS Wind and Solar Profile Development	5/17/2011	3/30/2012	229d
2	Task 2: Scenario Development and Analysis	5/17/2011	4/13/2012	239d
3	**Task 3: Scenario Simulation and Analysis**	**4/16/2012**	**10/31/2013**	**404d**
4	Literature Review	6/1/2012	10/31/2012	109d
5	**Task 3A: Operational Analysis**	**4/16/2012**	**5/31/2013**	**295d**
6	MAPS set-up, scenario simulations	4/16/2012	12/14/2012	175d
7	Task 3 Progress meeting at PJM	2/12/2013	2/12/2013	0d
8	Draft Report: LOLE, Reserves, Transmission	12/17/2012	5/1/2013	98d
9	Draft Report: Production costs, PROBE, Cycling analysis	12/17/2012	5/31/2013	120d
10	Task 3B: Market Analysis	6/3/2013	10/31/2013	109d
11	Task 4: Mitigation, Facilitation and Report	11/1/2013	12/5/2013	25d
12	Milestone: Final Report Review Meeting	12/6/2013	12/6/2013	0d



Study Scenarios

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

Hourly Analysis Key Findings

- 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.

Renewables and the Regulation Requirement

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%

imagination at work

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Primary Study Recommendations

- **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 limitation are technical, contractual, or otherwise, and investigate possible methods for improving ramp rate performance.*

Looking to the Future

- 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

Additional Information

- 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