PJM Renewable Integration Study

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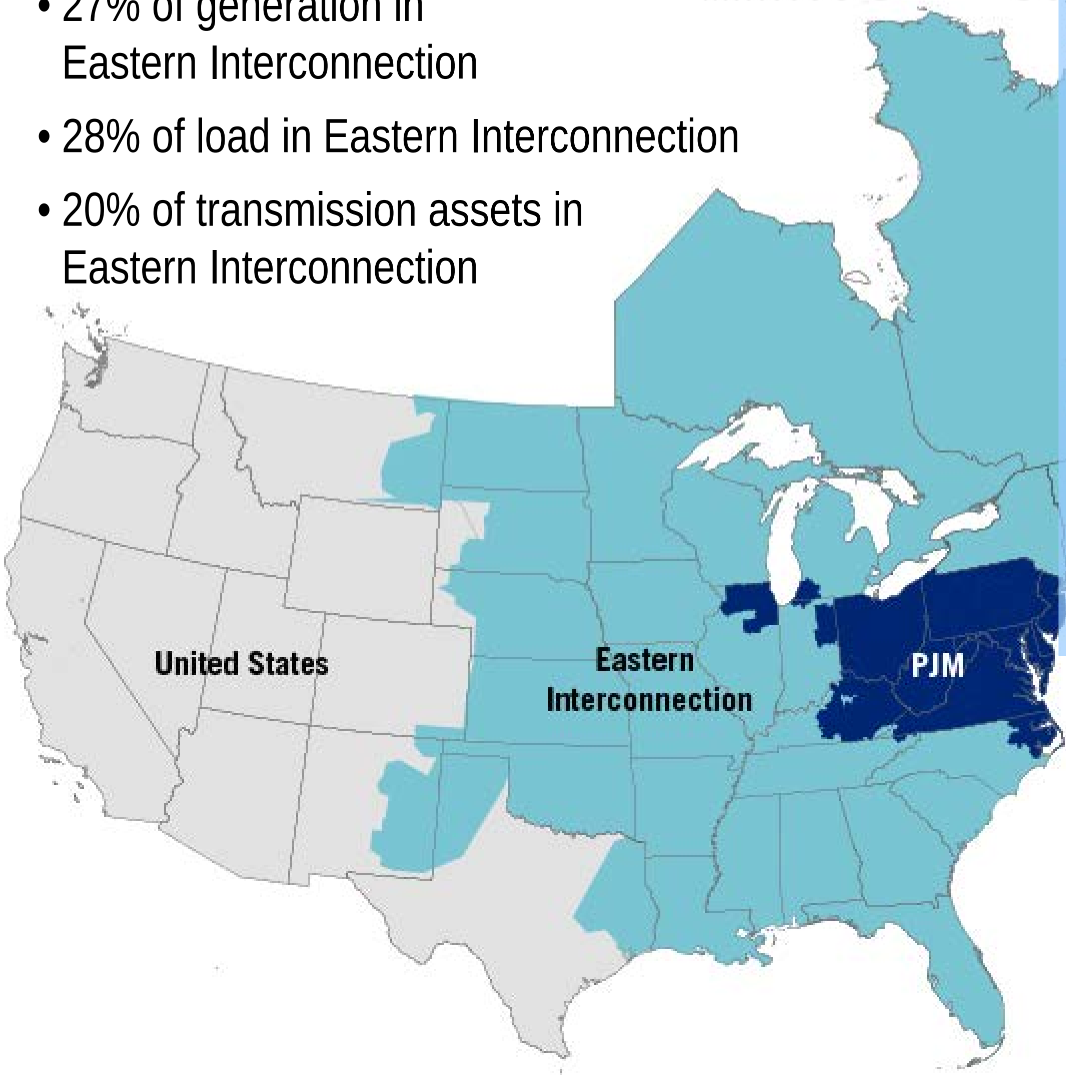
PJM as Part of the Eastern Interconnection

- 27% of generation in Eastern Interconnection
- 28% of load in Eastern Interconnection
- 20% of transmission assets in Eastern Interconnection

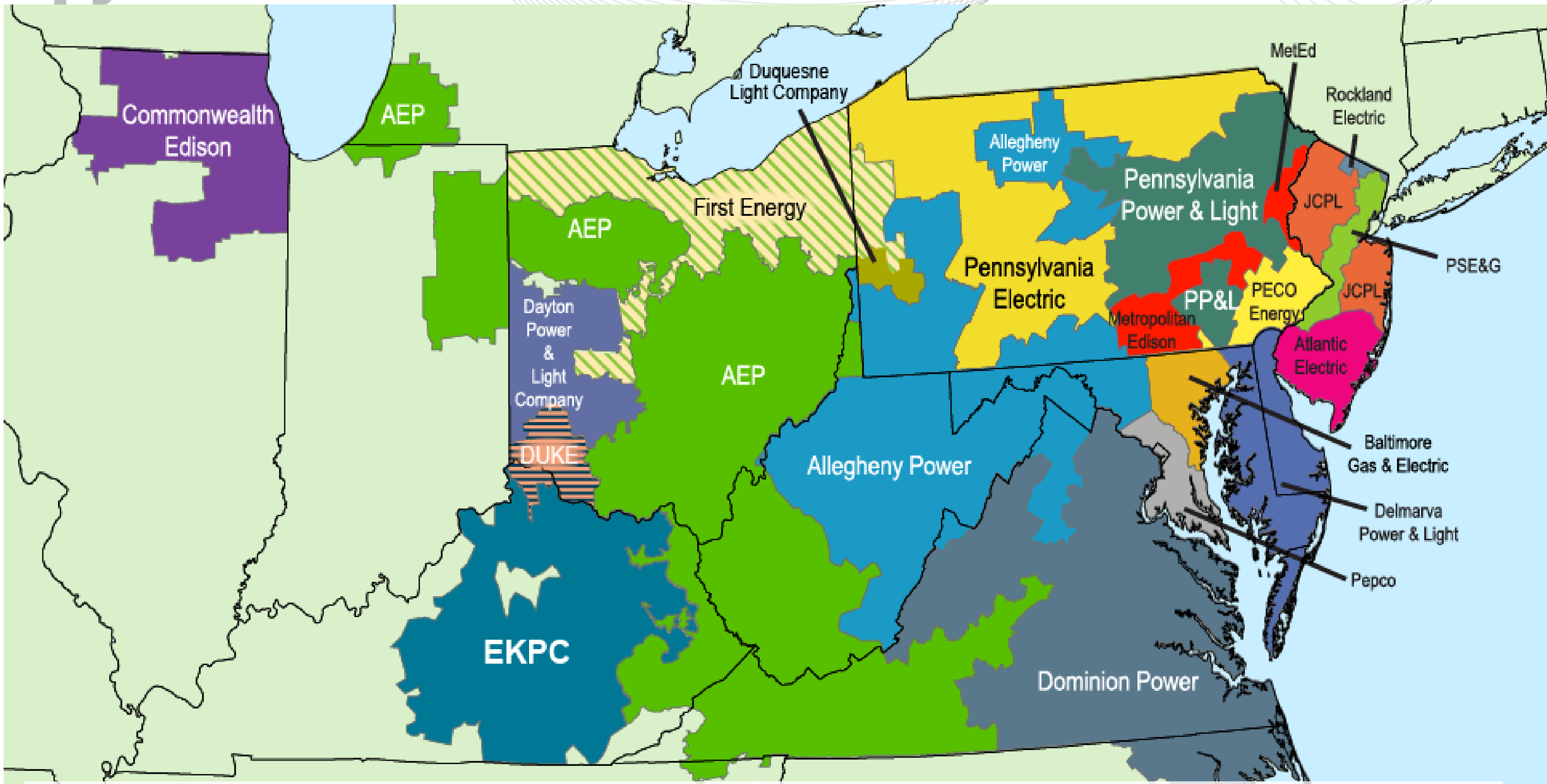


KEY STATISTICS	
PJM member companies	900+
millions of people served	61
peak load in megawatts	165,492
MWs of generating capacity	183,604
miles of transmission lines	62,556
2013 GWh of annual energy	791,089
generation sources	1,376
square miles of territory	243,417
area served	13 states + DC
externally facing tie lines	191

21% of U.S. GDP produced in PJM

As of 4/1/2014

PJM Evolution



PJM Expansion History

- 1927– Started three utility power pool
- 1997 – Started RTO with eight TOs
- June 2002 – AP Joined
- May 2004 - ComEd joined
- October 2004 – AEP/Dayton
- May 2005 – Dominion joined
- January 2006 – Duquesne joined
- June 2011 – FirstEnergy joined
- January 2012 – Duke joined
- June 2013 – EKPC joined

PJM is a Regional Transmission Organization (RTO) Focused on Three Things

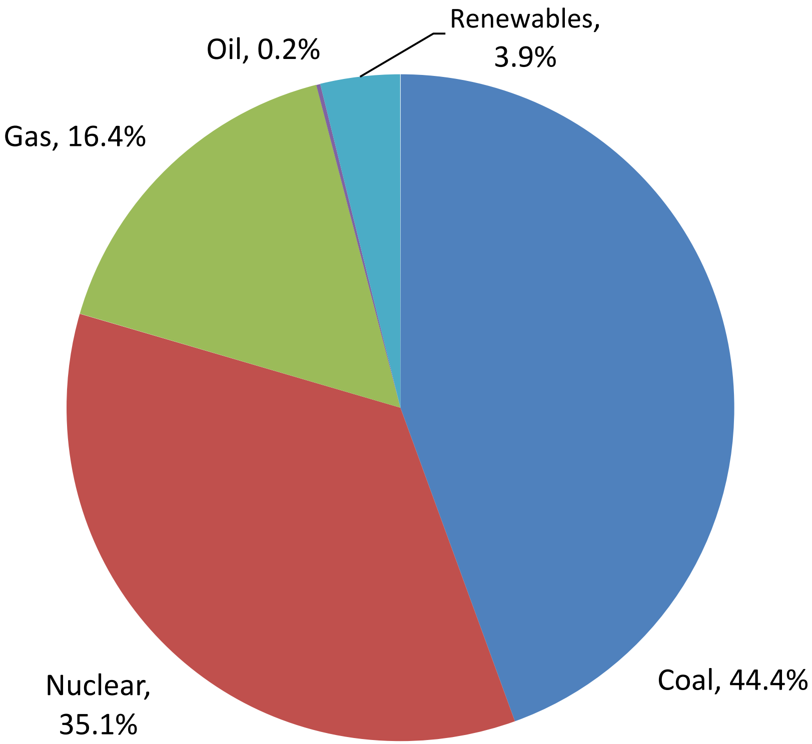
1 Reliability
- Grid Operations
- Supply/Demand Balance
- Transmission monitoring

2 Market Operation
- Energy
- Capacity
- Ancillary Services

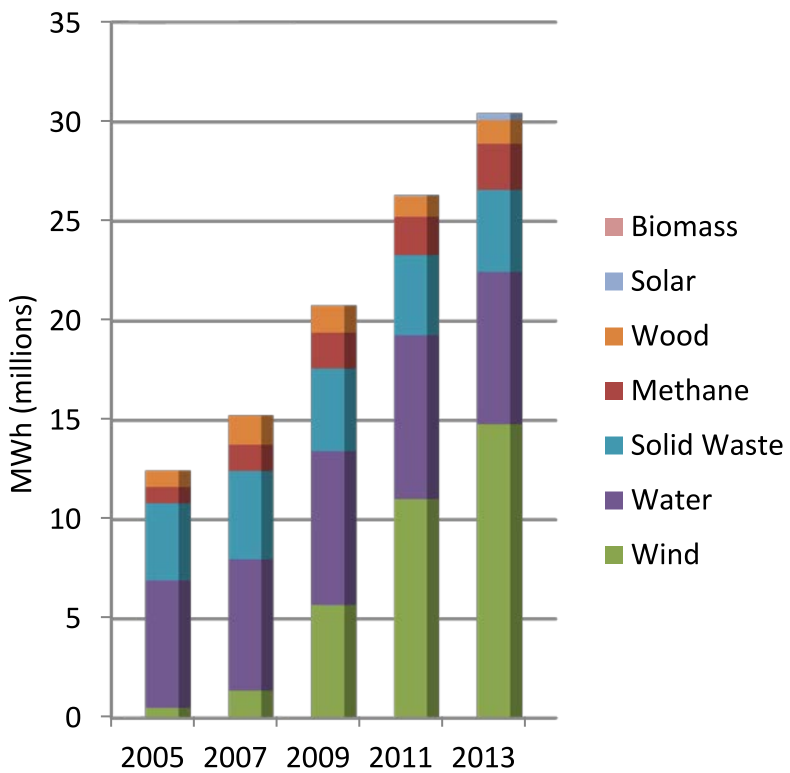
3 Regional Planning
- 15-Year Outlook

Percentage of Renewable Energy is Small but Growing

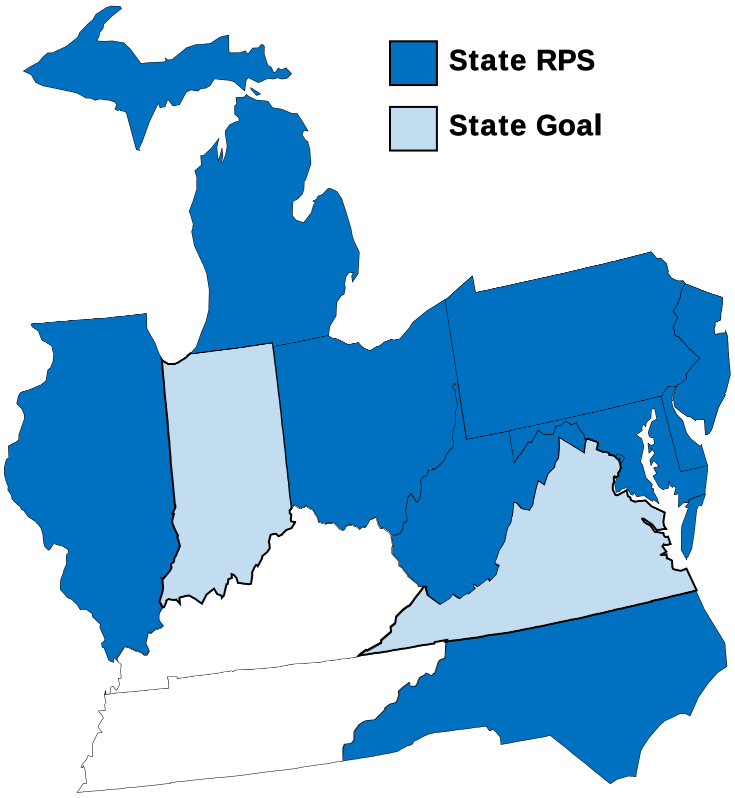
PJM Generation Mix - 2013



Renewable Energy in PJM



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 December 2013

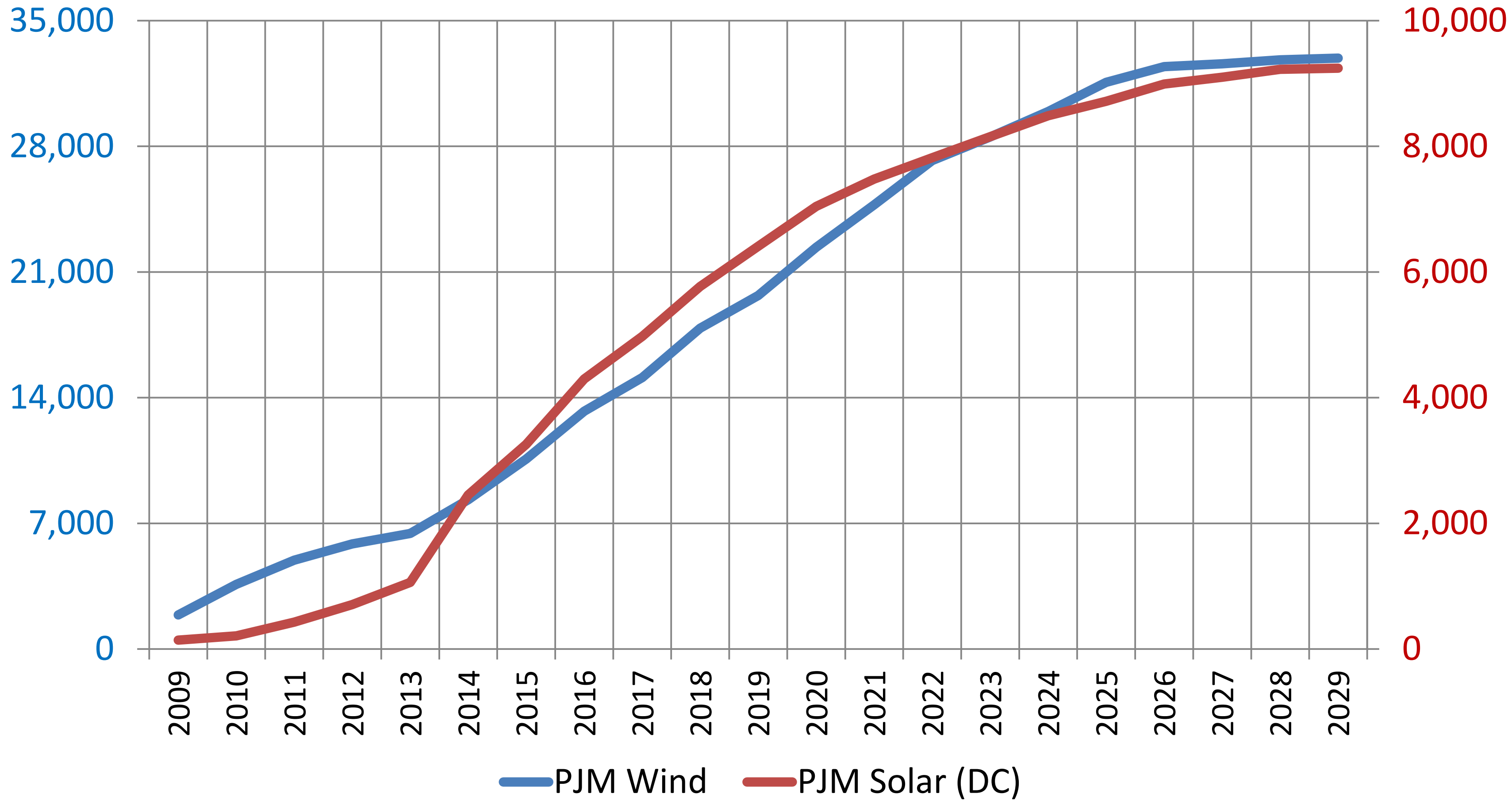
State RPS Targets:

- ☼ NJ: 20.38% by 2021
- ☼ MD: 20% by 2022
- ☼ DE: 25% by 2026
- ☼ DC: 20% by 2020
- ☼ PA: 18%** by 2020
- ☼ IL: 25% by 2025
- ☼ OH: 25%** by 2025
- ☼ NC: 12.5% by 2021 (IOUs)
- WV: 25%** by 2025
- MI: 10% + 1,100 MW by 2015
- VA: 15% by 2025
- IN: 10%** by 2025

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

Projected Renewable Energy Requirements in PJM

By 2029: 122,000 GWh of renewable energy, 13.4% of PJM annual net energy (**33 GW** of wind and **9.2 GW** of solar)



- **Energy Markets / Operations**
  - Implemented a centralized wind power forecast service.
  - Implemented changes to improve wind resource dispatch / control.
  - Demand Response / Price Responsive Demand improves operational flexibility
  - Frequency Regulation – incents 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 requirements for wind and solar being evaluated
- **Evaluating Potential Grid Impacts**
  - Initiated a PJM Renewable Integration Study (PRIS) to assess grid impacts
- **Advanced Technology Research Program**
  - Pilot programs to evaluate new technologies and remove barriers to participation in PJM markets and operations.

Study Objective

- This study was initiated at the request of PJM stakeholders.
- Study Objective:
  - Determine, for the PJM balancing area, the operational, planning, and market effects of large-scale integration of wind power as well as mitigation/facilitation measures available to PJM.
  - Make recommendations for the implementation of such mitigation/facilitation measures.
- Disclaimer: The purpose of the study is to assess impacts to the grid if additional wind and solar are connected. It is not an analysis of the economics of those resources, therefore quantifying the capital investment required to construct additional wind and solar is beyond the scope of this study.

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

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

- 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.

Summary of New Transmission Lines and Upgrades

Scenario	765 kV New Lines (Miles)	765 kV Upgrades (Miles)	500 kV New Lines (Miles)	500 kV Upgrades (Miles)	345 kV New Lines (Miles)	345 kV Upgrades (Miles)	230 kV New Lines (Miles)	230 kV Upgrades (Miles)	Total (Miles)	Total Cost (Billion)	Total Congestion Cost (Billion)
2% BAU	0	0	0	0	0	0	0	0	0	$0	$1.9
14% RPS	260	0	42	61	352	35	0	4	754	$3.7	$4.0
20% Low Offshore Best Onshore	260	0	42	61	416	122	0	4	905	$4.1	$4.0
20% Low Offshore Dispersed Onshore	260	0	42	61	373	35	0	49	820	$3.8	$4.9
20% High Offshore Best Onshore	260	0	112	61	363	122	17	4	939	$4.4	$4.3
20% High Solar Best Onshore	260	0	42	61	365	122	0	4	854	$3.9	$3.3
30% Low Offshore Best Onshore	1800	0	42	61	796	129	44	74	2946	$13.7	$5.2
30% Low Offshore Dispersed Onshore	430	0	42	61	384	166	44	55	1182	$5.0	$6.3
30% High Offshore Best Onshore	1220	0	223	105	424	35	14	29	2050	$10.9	$5.3
30% High Solar Best Onshore	1090	0	42	61	386	122	4	4	1709	$8	$5.6

Estimated Regulation Requirements for Each Scenario

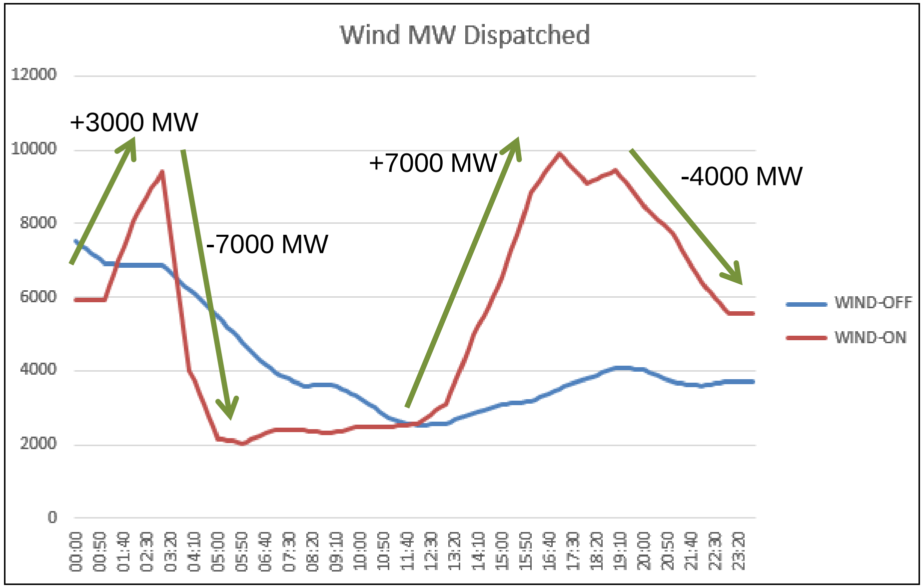
- The amount of additional regulation calculated for each hour depends on:
  - The amount of regulation carried for load alone
  - The aggregate wind and PV generation production level
    - The statistics show that wind production varies more when production from 40% to 60% of maximum and PV production varies more when production is from 10% to 20% of maximum

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

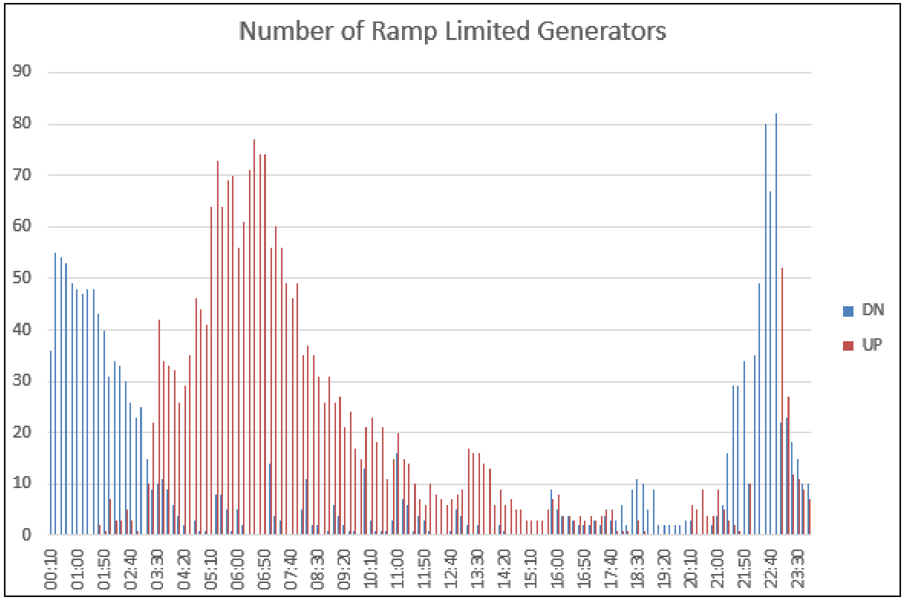
- Fifty particularly challenging days across the 2%, 14%, 20%, and 30% profiles were examined in more detail through sub-hourly market simulations.
- Key findings from the sub-hourly simulations:
  - In general, all the simulations of challenging days revealed successful operation of the PJM real-time market.
  - Higher penetrations of renewable energy (20% and 30%) create operational patterns (e.g., for CT usage) that are significantly different from what is common today.

A Sub-Hourly Run Example
May 26 – 20% HOBO/LOBO/LODO

On-Shore Wind Ramps

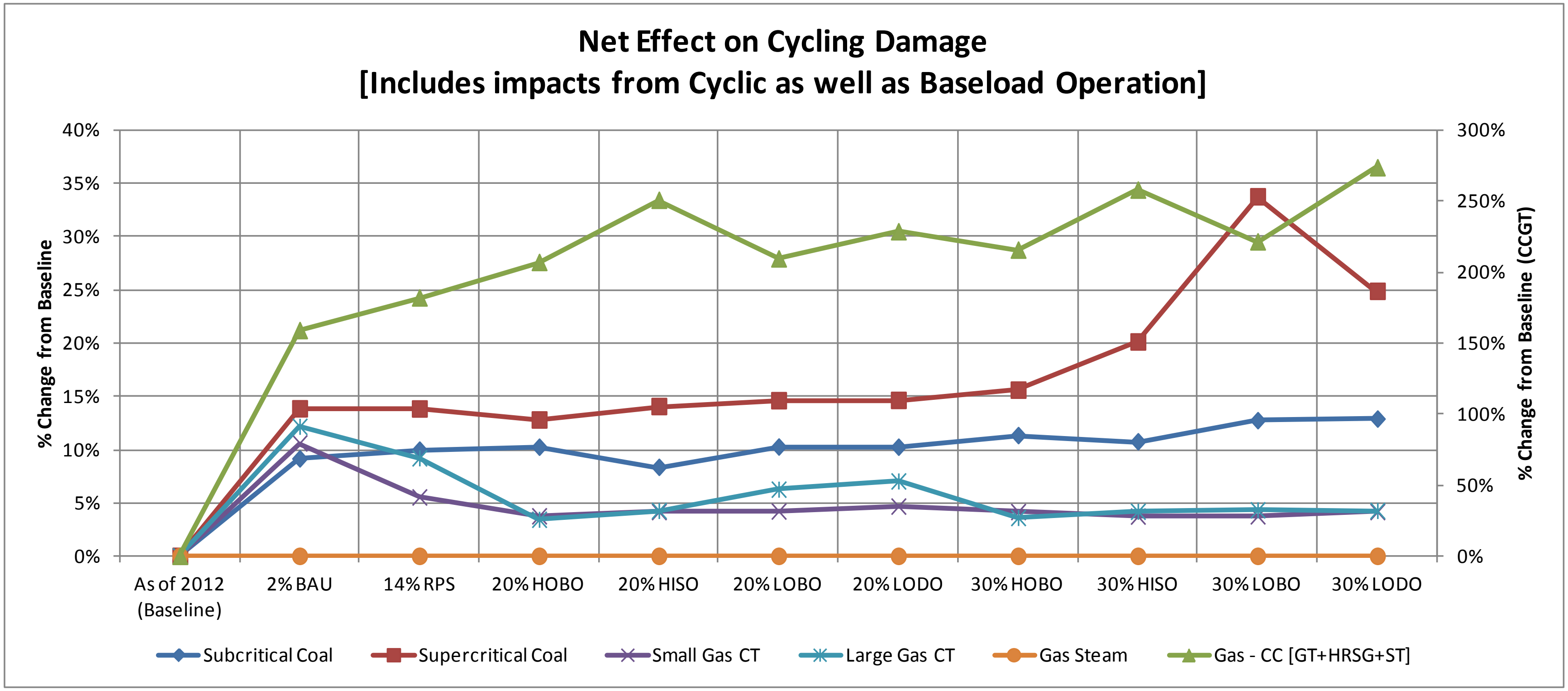


Ramp-Limited Generation



Cycling Analysis – Damage by Unit Type

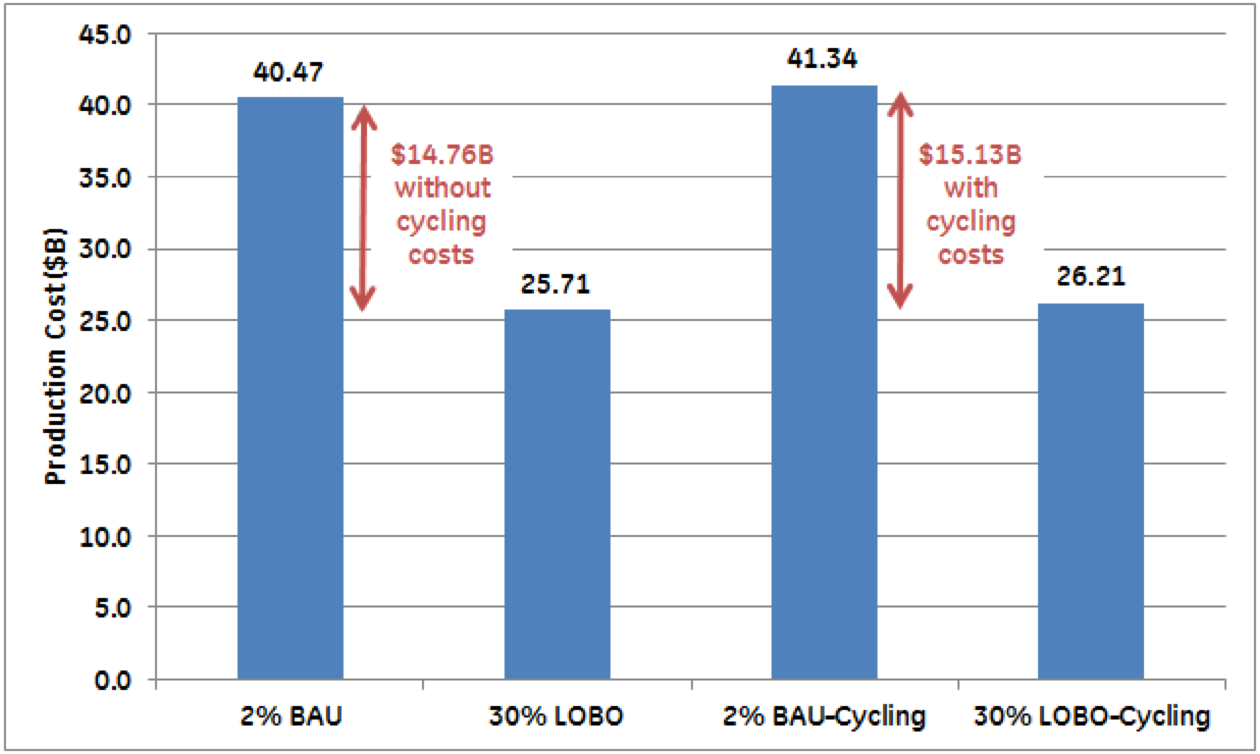
- Increased cycling will cause generator damage costing hundreds of millions annually.
- Biggest impacts:
  - Combined Cycle GT units – primarily due to on/off cycles
  - Supercritical Coal units – primarily due to load follow cycles



Baseline = Historical operation from 2000-2012

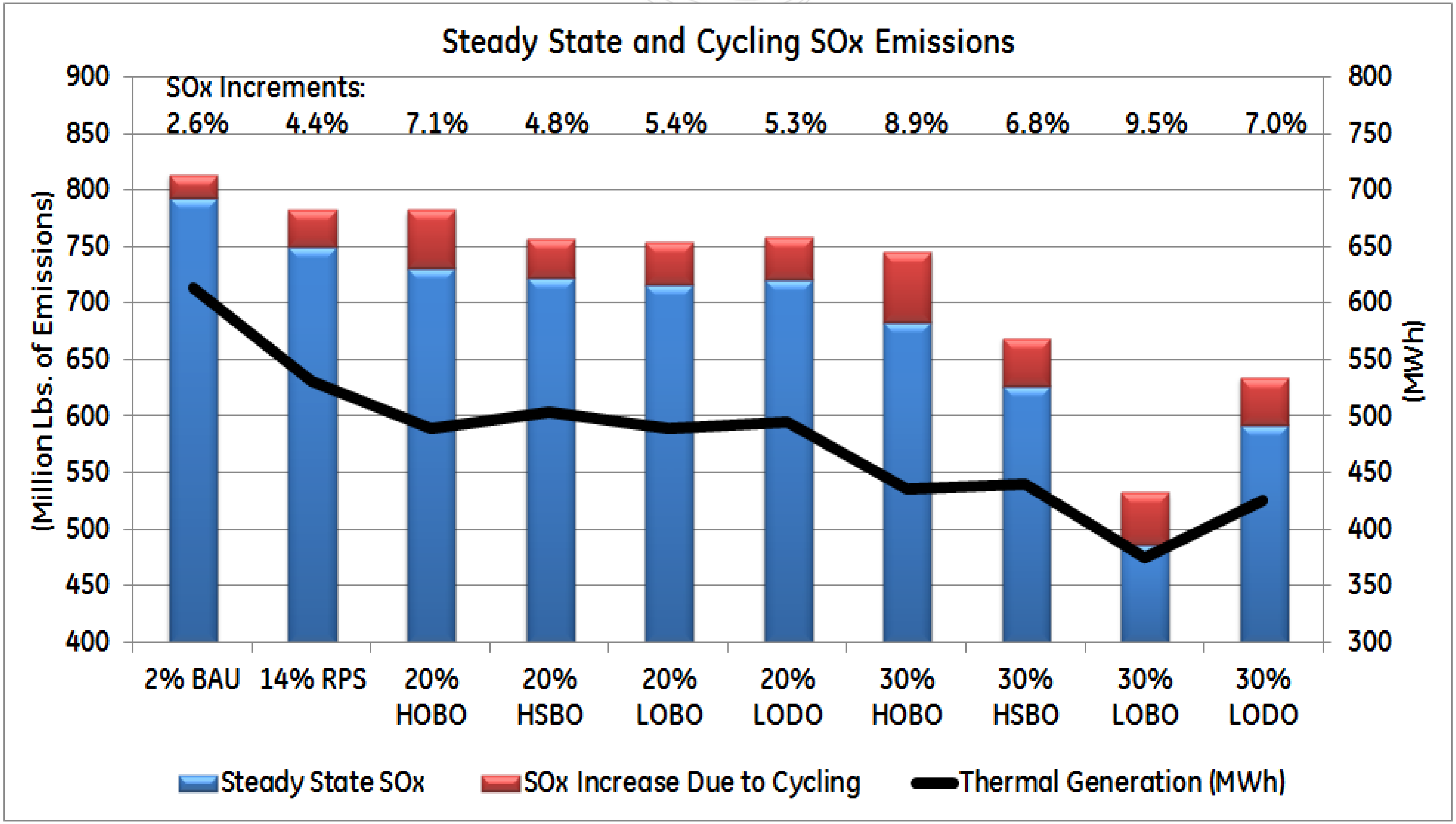
Cycling Costs Increase
(however, they are small compared to Fuel Cost Savings)

- Taking into consideration the "extra" wear-and-tear duty imposed by increased unit cycling, for the 30% LOBO scenario production costs increase from $25.71B to $26.21B, i.e., $0.50B (**$500M**) annually.
- These increased cycling costs are about **3.3%** of production cost savings ($15.13B)



SOx Emissions for Study Scenarios With and Without Cycling Effects Included

On/off cycling and load-following increases emissions compared to steady state levels, but **not dramatically**.



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.*