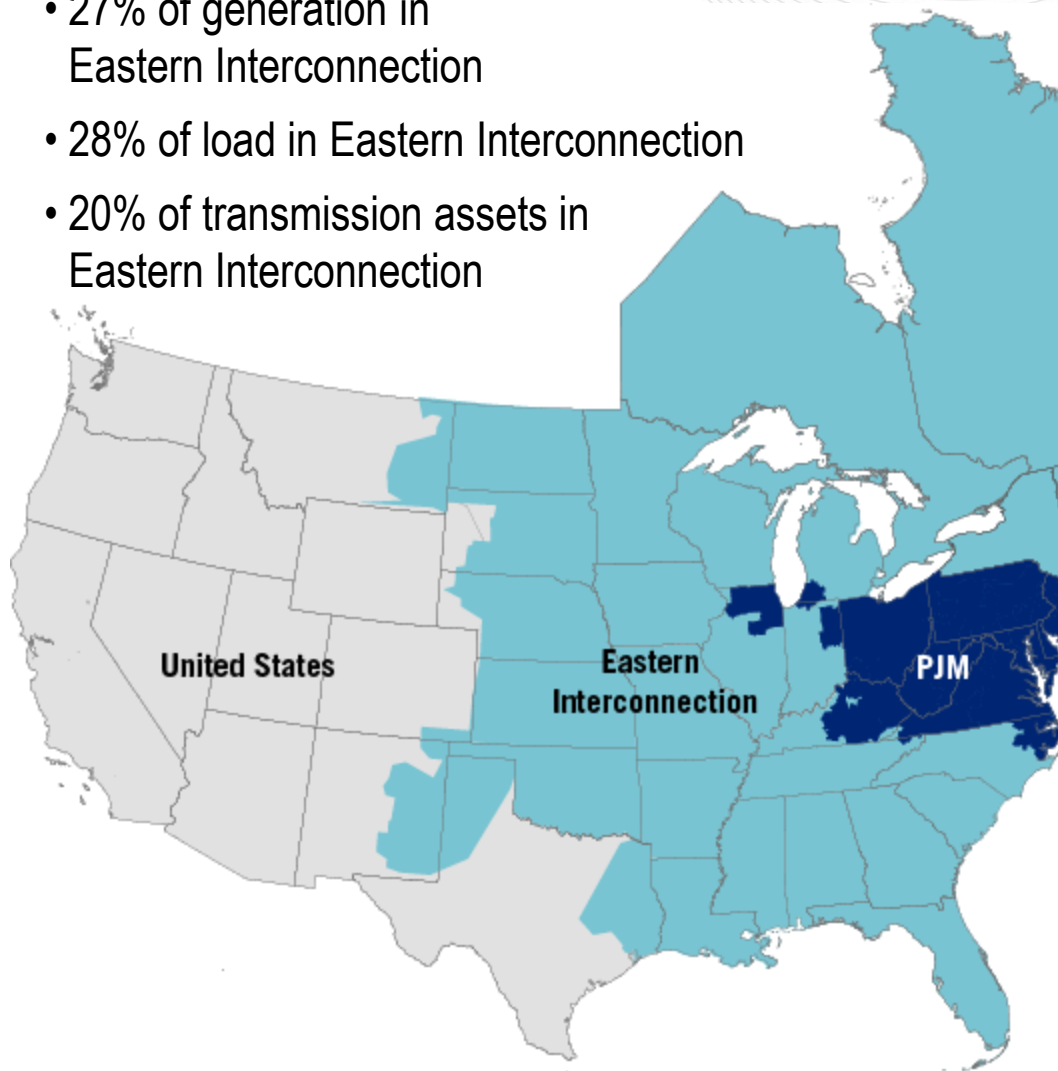




PJM Renewable Integration

National Conference of State Legislatures
May 29, 2014

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



KEY STATISTICS

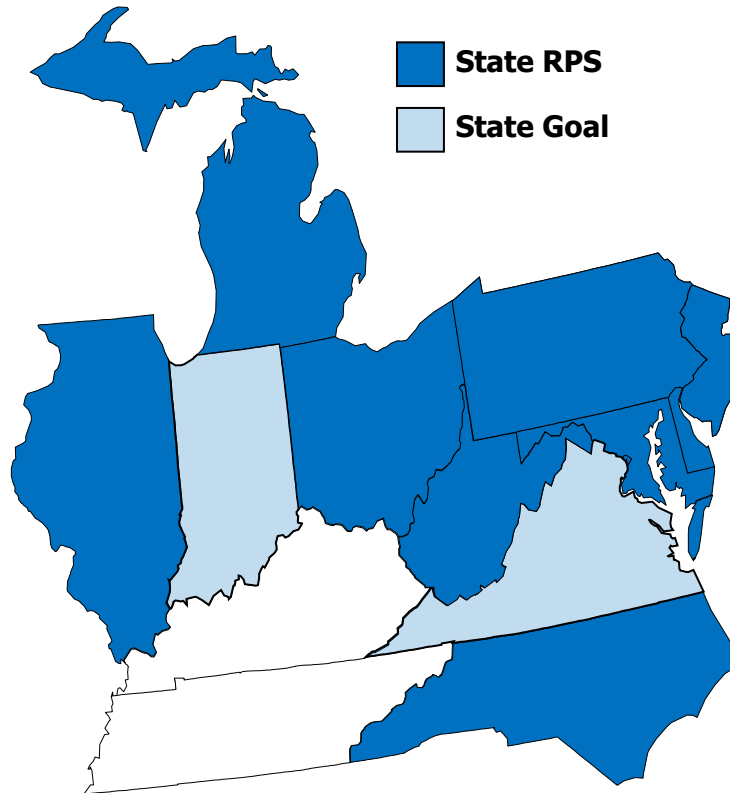
PJM member companies	900+
millions of people served	61
peak load in megawatts	165,492
MW of generating capacity	183,604
miles of transmission lines	62,556
2013 GWh of annual energy generation sources	791,089
square miles of territory area served	243,417
externally facing tie lines	13 states + DC
	191

**21% of U.S. GDP
produced in PJM**

As of 4/1/2014

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: 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

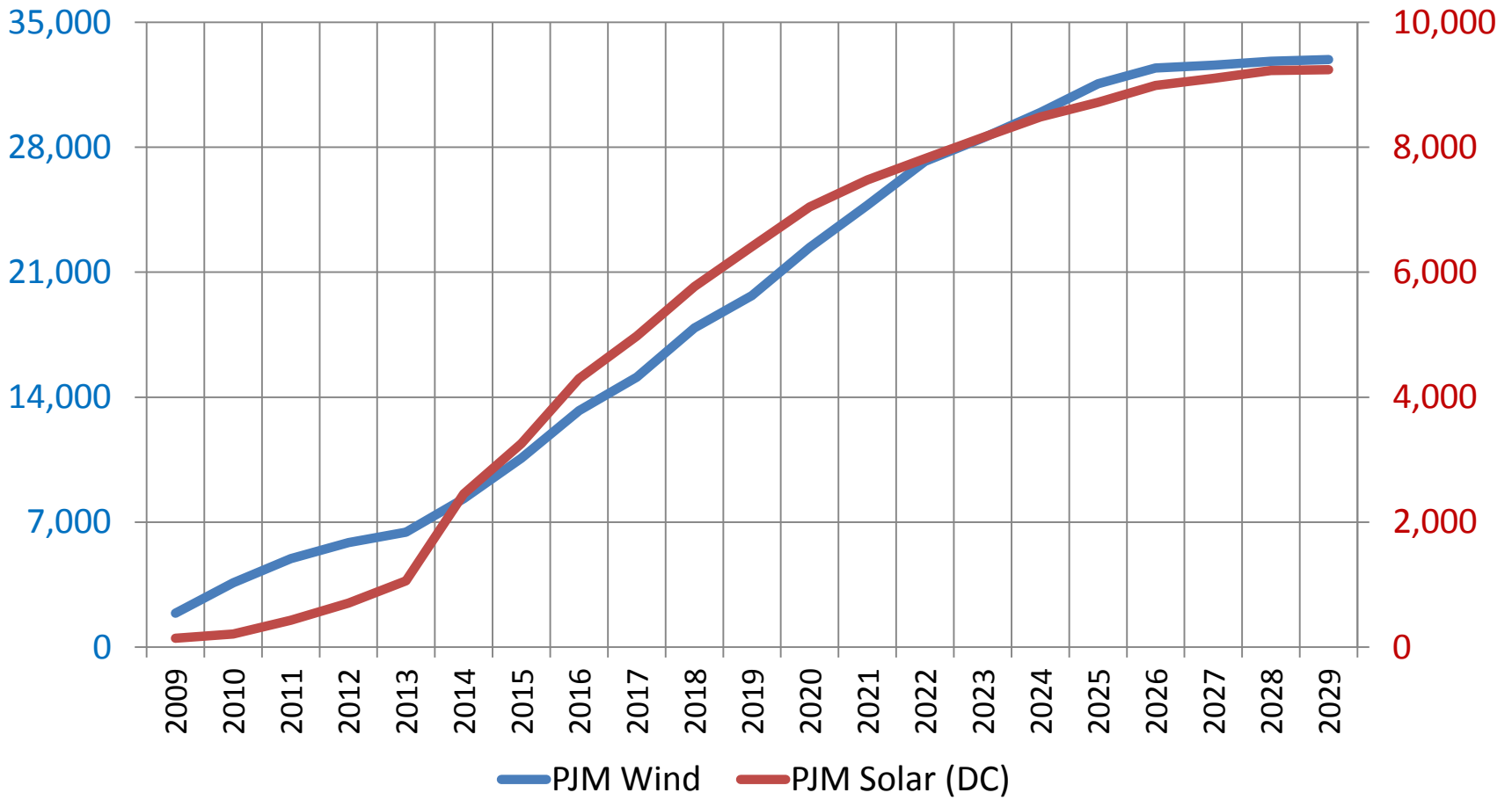
☀ Minimum solar requirement

** 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)



ISOs and RTOs 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 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.
- 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.

- 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



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

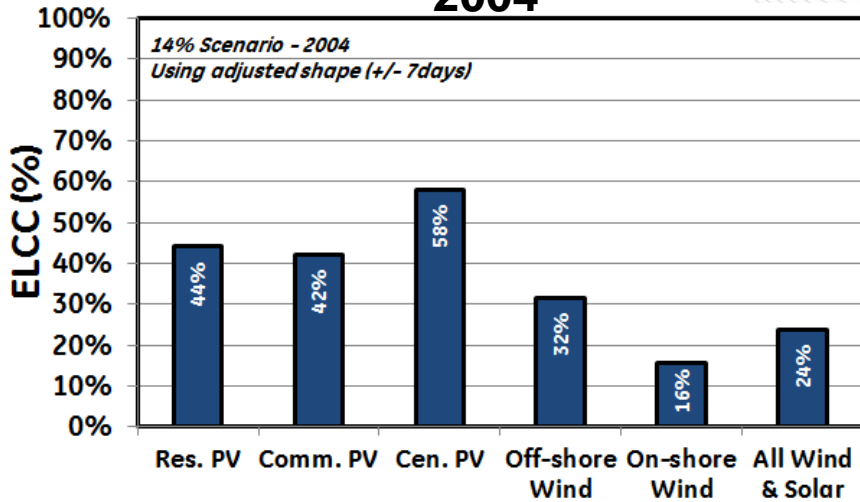
ID	Task Name	Start	Finish	Duration	Q11		Q311			Q411			Q12			Q22			Q32			Q42			Q13			Q23			Q33			Q43		
					May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Task1: PRIS Wind and Solar Profile Development	5/17/2011	3/30/2012	229d	[Blue bar spanning from May 2011 to March 2012]																															
2	Task2: Scenario Development and Analysis	5/17/2011	4/13/2012	239d	[Blue bar spanning from May 2011 to April 2012]																															
3	Task3: Scenario Simulation and Analysis	4/16/2012	10/31/2013	404d	[Blue bar spanning from April 2012 to October 2013]																															
4	Literature Review	6/1/2012	10/31/2012	109d	[Blue bar spanning from June 2012 to October 2012]																															
5	Task3A: Operational Analysis	4/16/2012	5/31/2013	295d	[Blue bar spanning from April 2012 to May 2013]																															
6	MAP Set-up scenarios simulations	4/16/2012	12/14/2012	175d	[Blue bar spanning from April 2012 to December 2012]																															
7	Task3 Progress meeting at PJM	2/12/2013	2/12/2013	0d	[Single point in February 2013]																															
8	Draft Report LOLE, Reserves, Transmission	12/17/2012	5/1/2013	99d	[Blue bar spanning from December 2012 to May 2013]																															
9	Draft Report Production costs, FROBE, Cycling analysis	12/17/2012	5/31/2013	120d	[Blue bar spanning from December 2012 to May 2013]																															
10	Task3B Market Analysis	6/3/2013	10/31/2013	109d	[Blue bar spanning from June 2013 to October 2013]																															
11	Task4 Migration, Facilitation and Report	11/1/2013	12/5/2013	25d	[Blue bar spanning from November 2013 to December 2013]																															
12	Milestone: Final Report Review Meeting	12/6/2013	12/6/2013	0d	[Single point in December 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 wind 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 wind with best onshore wind
30% HSBO	30%	179 / 97	High Solar + Best Onshore	1 year	High solar with best onshore wind

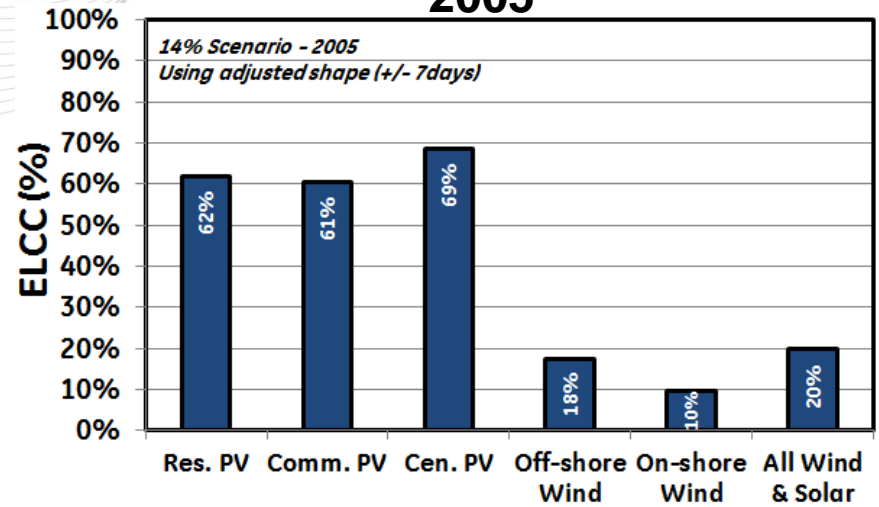
- The PJM system, with additional reserves and transmission build-out, could handle renewable penetration levels up to 30%.
- The principal impacts of higher penetration of renewable energy into the grid include:
 - Lower Coal and CCGT generation under all scenarios
 - Lower emissions of criteria pollutants 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.

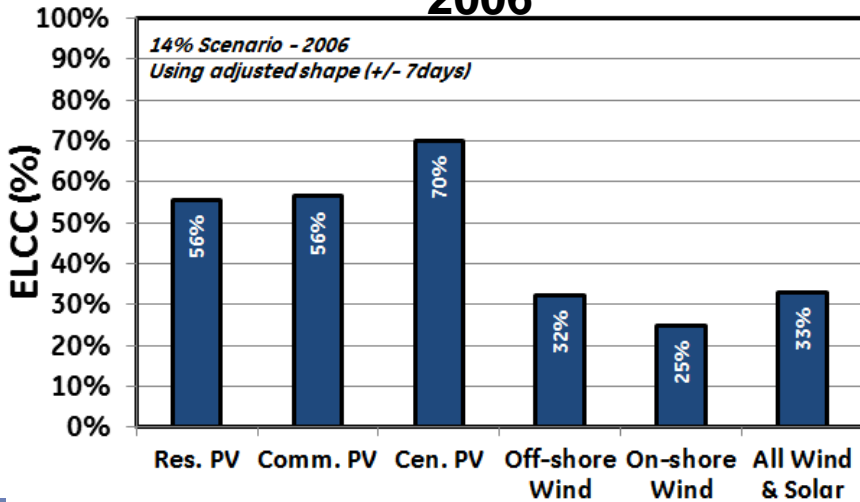
2004



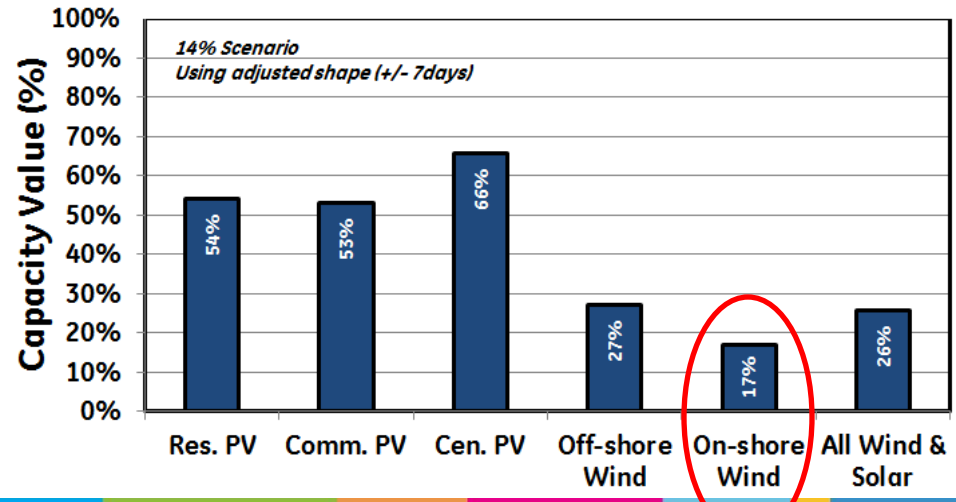
2005



2006



Average of three years



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

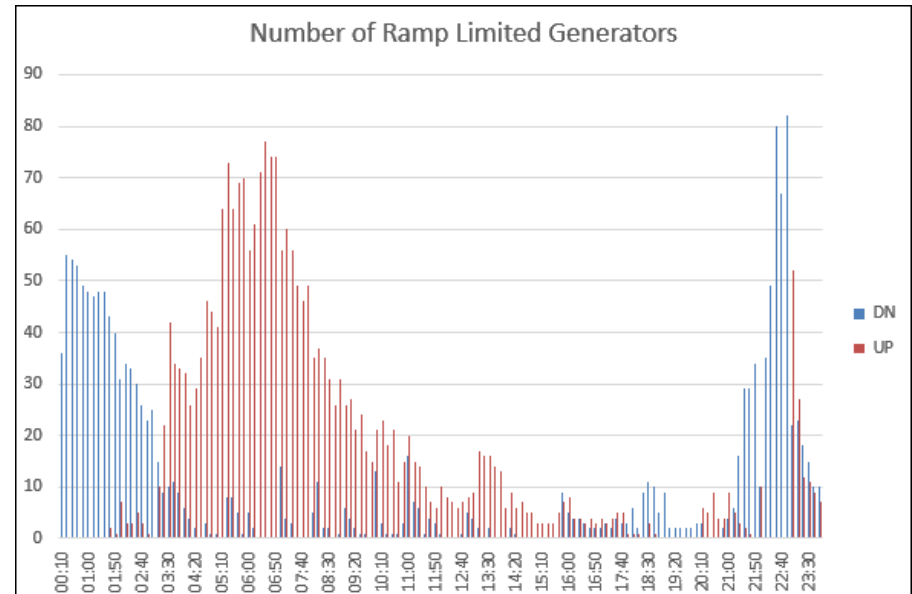
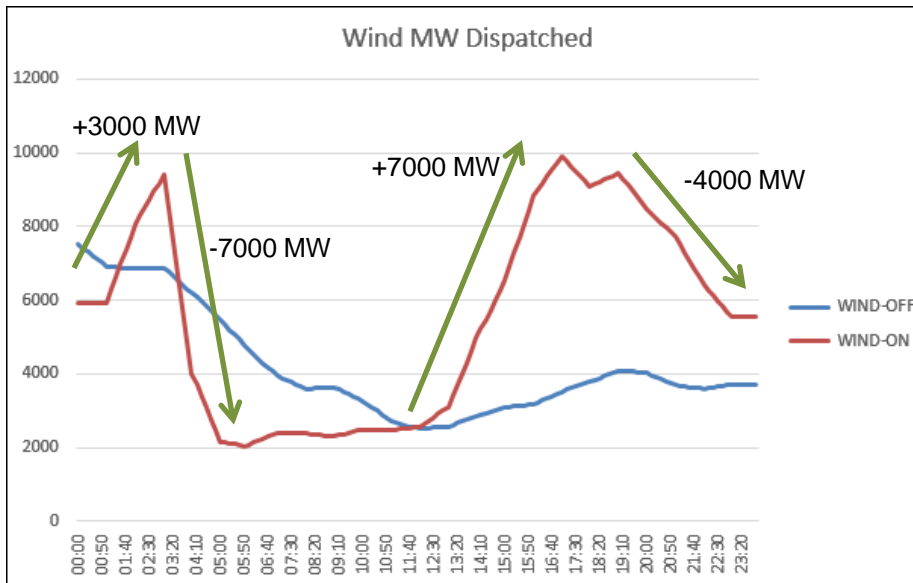
- The amount of additional regulation calculated for each hour depends on:
 - The amount of regulation carried for load alone
 - The aggregate wind and PV generation production level

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%

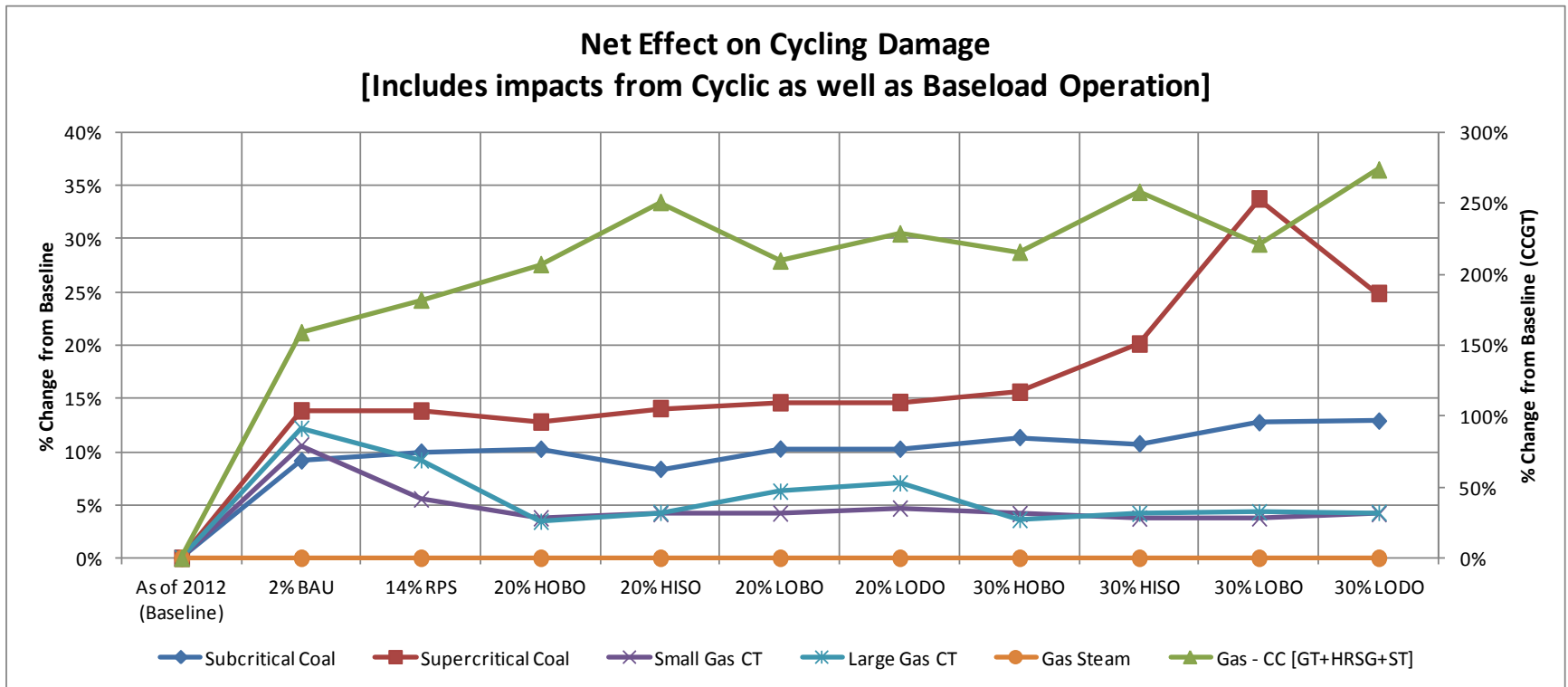
- Fifty particularly challenging days across the 2%, 14%, 20%, and 30% profiles were examined in more detail through sub-hourly market simulations.
- Key findings from the sub-hourly simulations:
 - In general, all the simulations of challenging days revealed successful operation of the PJM real-time market.
 - ***CTs contributed significantly to this outcome.*** *The study generation portfolio includes CT units with an aggregate capacity of 64 GW, more than double the existing CT capacity.*
 - The level of difficulty for real-time operations largely depends on the day-ahead unit commitment, which in turn depends on an accurate wind and solar power forecast.
 - 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.

On-Shore Wind Ramps

Ramp-Limited Generation



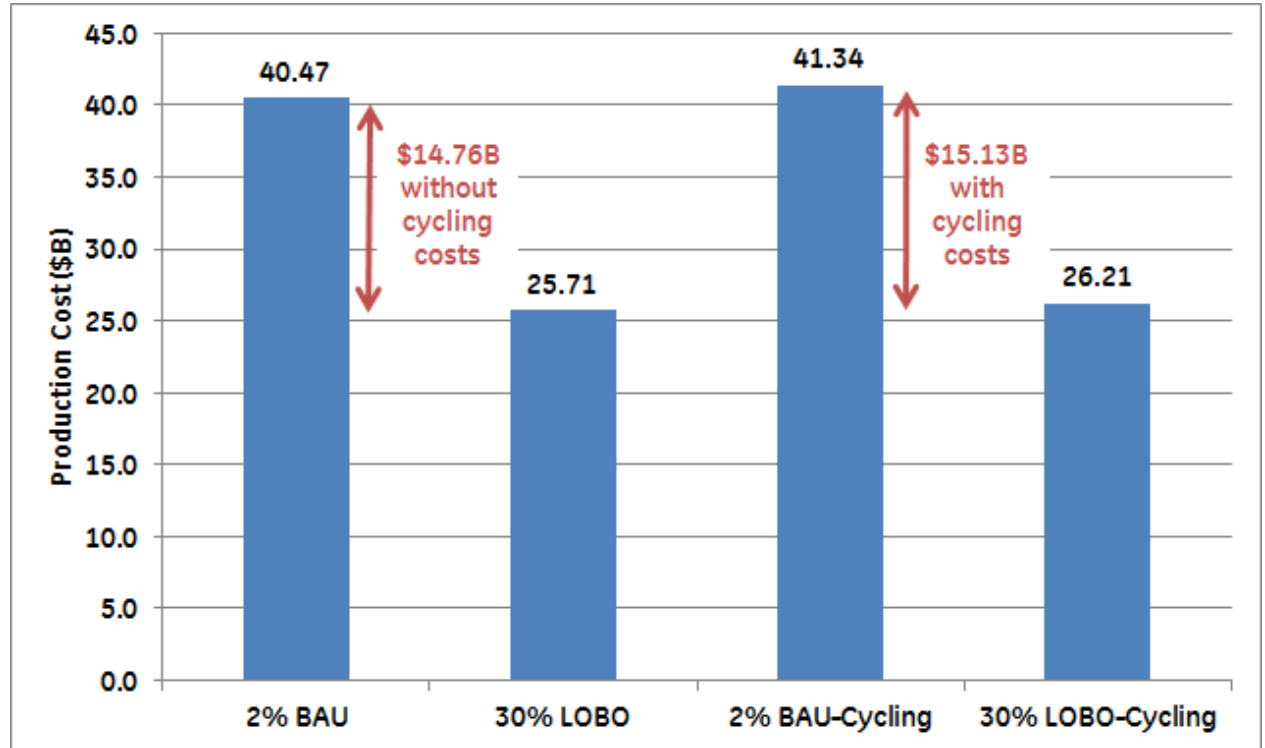
- Increased cycling will cause generator damage costing hundreds of millions annually.
- Biggest impacts:
 - Combined Cycle GT units – primarily due to on/off cycles
 - Supercritical Coal units – primarily due to load follow cycles



Baseline = Historical operation from 2000-2012

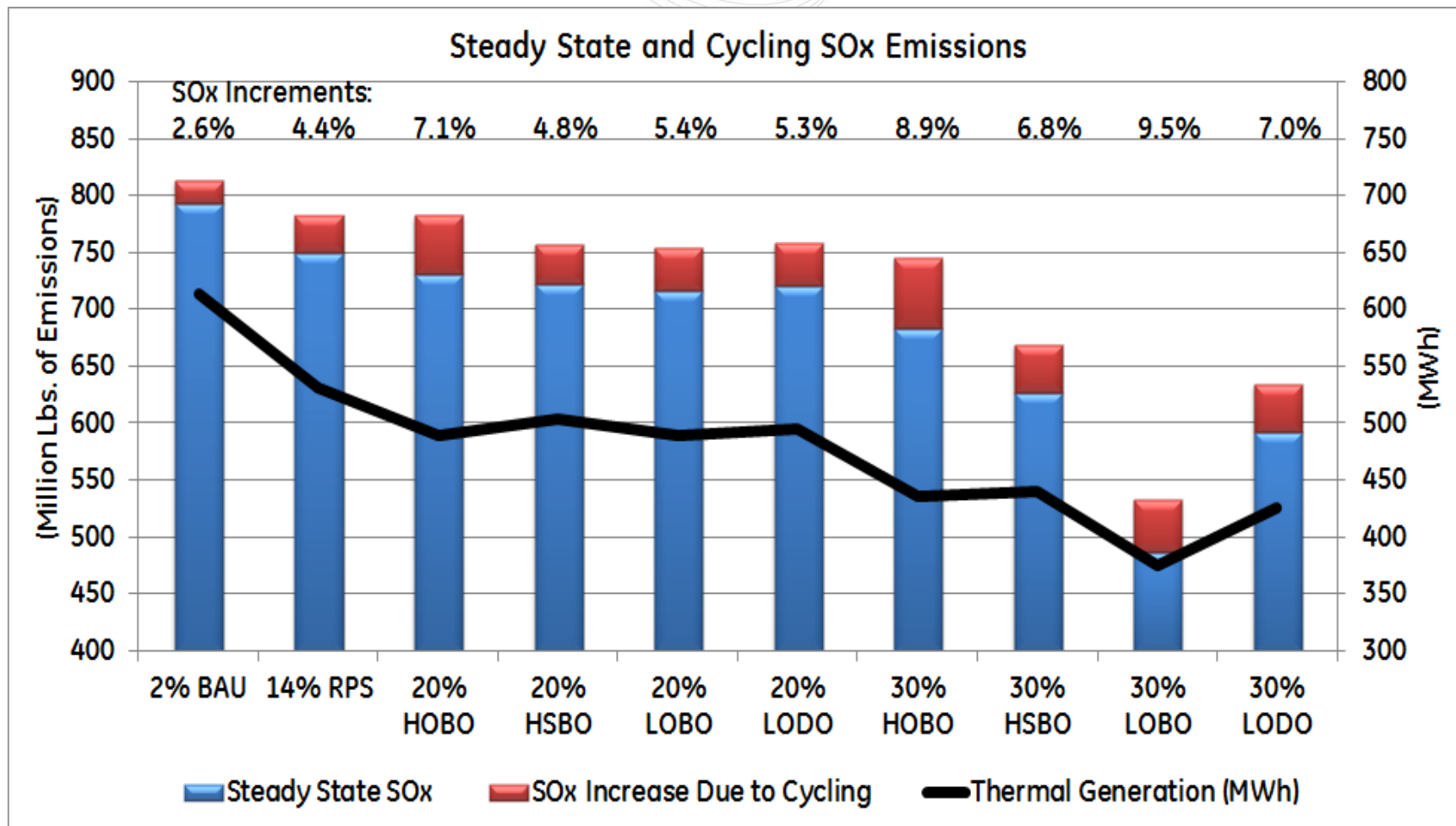
Cycling Costs Small in Comparison to Fuel Costs

- 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**.



- **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.*

- PJM's Intermittent Resources Task Force (IRTF) will review recommendations from the Renewable Integration Study and present to the Market Implementation Committee (MIC) a plan for how the recommendations ought to be addressed.
- Proposed approach presented to MIC by August 2014.