Offshore Transmission Study Group
Phase 1 Results

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Presented to Independent State Agencies Committee (ISAC)

July 29, 2021

Points about the study

- Study intends to be responsive to OPSI request
- Study intends to be directional at this stage
- Study identifies costs and *location* of upgrades, not ratepayers responsible for costs of upgrades
- Study is advisory:
  - Intends to provide data that may display options and aid in state decision-making
  - It is up to each state if they wish for PJM to continue further analysis (Phase 2)
  - Further analysis (Phase 2) does not commit to further action
  - As today, OSW may always integrate exclusively through the PJM generation interconnection queue

Offshore Transmission Study Group Recap

- PJM and interested state agencies began meeting in October 2020 as an independent effort to consider offshore wind public policy needs.
  - Also factored in all PJM state RPS requirements
- The goal is to analyze and identify transmission solutions across the PJM region to accommodate the coastal states' offshore wind goals and PJM states' RPS requirements.
- PJM collaboration with states determined initial ***five*** scenarios to model.
  - Originally six scenarios, removed Scenario #3 based on pending legislation that was withdrawn
  - Refined VA's OSW injections based on preliminary results

Schedule

2020 | **2021**

Education

- State offshore wind targets
- Interconnection process
- Technical components of OSW turbines
- Transmission system overview
- Cost allocation
- Order 1000 and the State Agreement Approach
- Environmental and social considerations for OSW development

Phase 1 Scenario Development

- OTSG Sessions
- 1:1 meetings with coastal state agencies
- PJM feedback and coordination
- Scenario finalization

Simulation & Analysis

Initial Results

July

Phase 2 Scenario Development

Final Report

Modeling and Analysis Overview

Consistent with PJM RTEP analysis

Powerflow reliability analysis for onshore transmission system

- Summer, winter and light load
- Simulated for years 2027 and 2035

Examined 100 kV and up across the entire PJM footprint

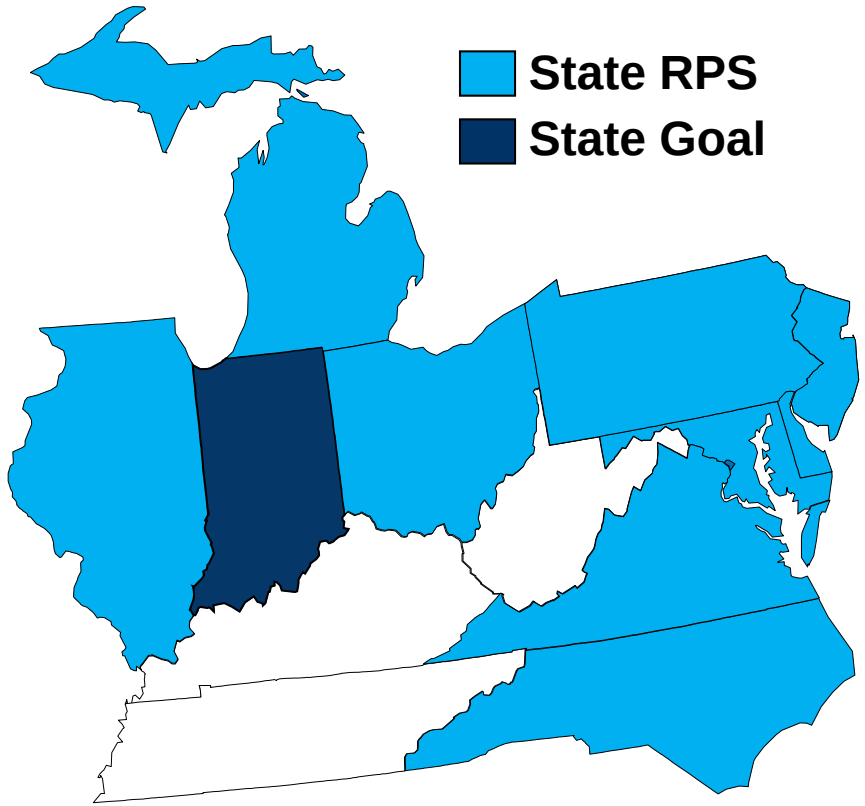
Only identified thermal violations

Transmission line conductor limits were used to establish transmission line overloads

Included RPS targets and carve-outs for each PJM state, and modeled each state meeting its RPS target by required date

PJM State RPS Targets

PJM modeled each state's RPS requirements as being met by the years considered in this study, and also included all known resource-specific carve-outs.



State RPS Targets*

- ☼ **NJ:** 50% by 2030**
- ☼ **MD:** 50% by 2030
- ☼ **DE:** 40% by 2035
- ☼ **DC:** 100% by 2032
- ☼ **PA:** 18% by 2021***
- ☼ **IL:** 25% by 2025-26
- ☼ **VA:** 100% by 2045/2050 (IOUs)
- ☼ **NC:** 12.5% by 2021 (IOUs)
- **OH:** 8.5% by 2026
- **MI:** 15% by 2021
- **IN:** 10% by 2025***

☼ Minimum solar requirement

* Targets may change over time, these are recent representative snapshot values

** Includes an additional 2.5% of Class II resources each year

*** Includes non-renewable "alternative" energy resources

Considerations to Phase 1 Results

Announced deactivations as of Oct. 1, 2020

Does not include any subsequently announced deactivations, including those post-2022/2023 BRA

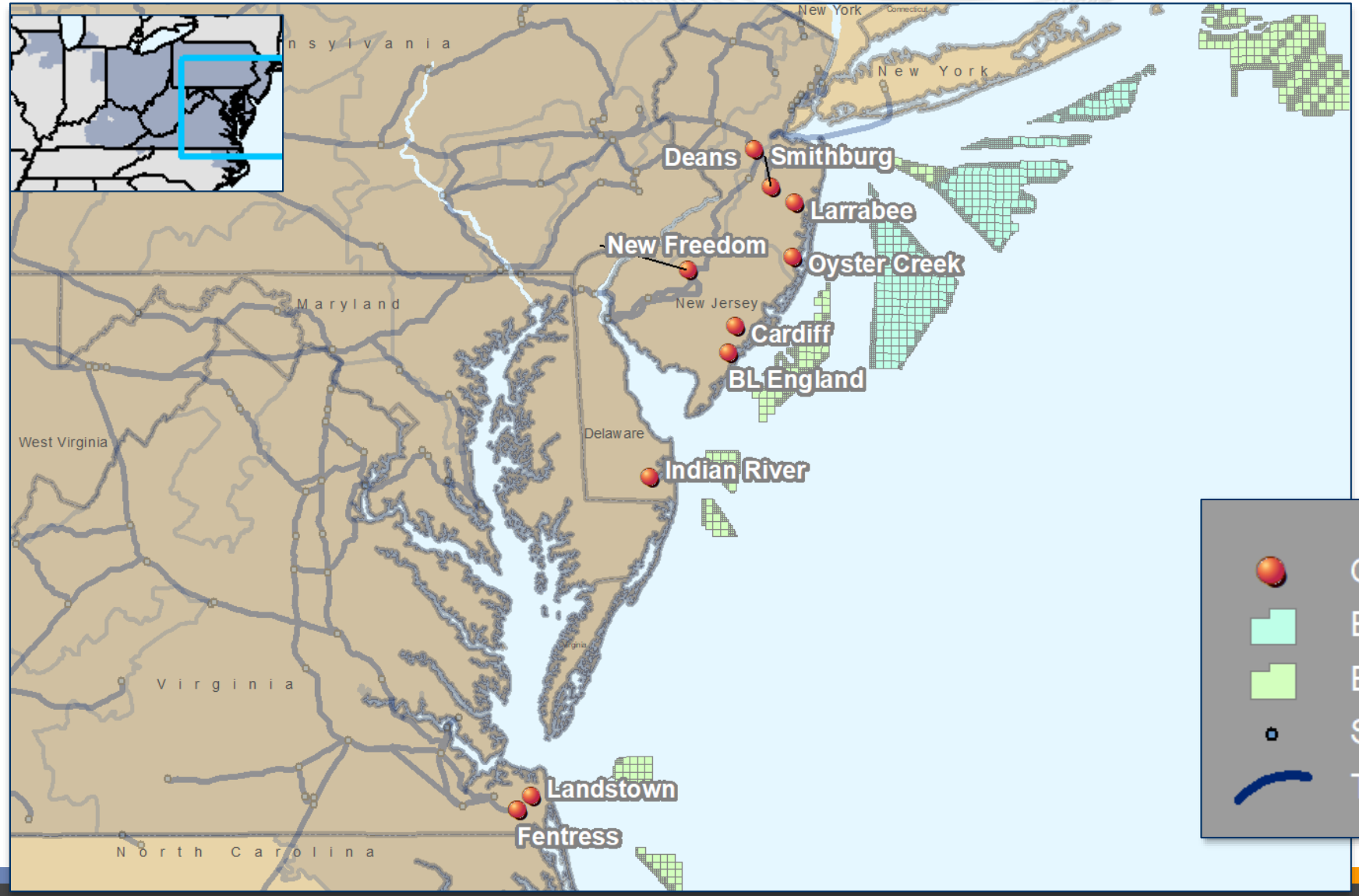
Model for Phase 1 included Transource 9A

2020 RTEP modeling

Only considered 100 kV+ onshore network upgrade requirements

Cost estimates *do not* include generator lead-lines or offshore facilities

Scenario Injection Locations



Scenario 1 Results

Scenario 1 – 2027 RPS Target

Offshore Wind Injections: 6,416 MW

DE & MD

Indian River 230 kV

248 MW | 520 MW*

NC & VA

Fentress 500 kV

2,600 MW

NJ

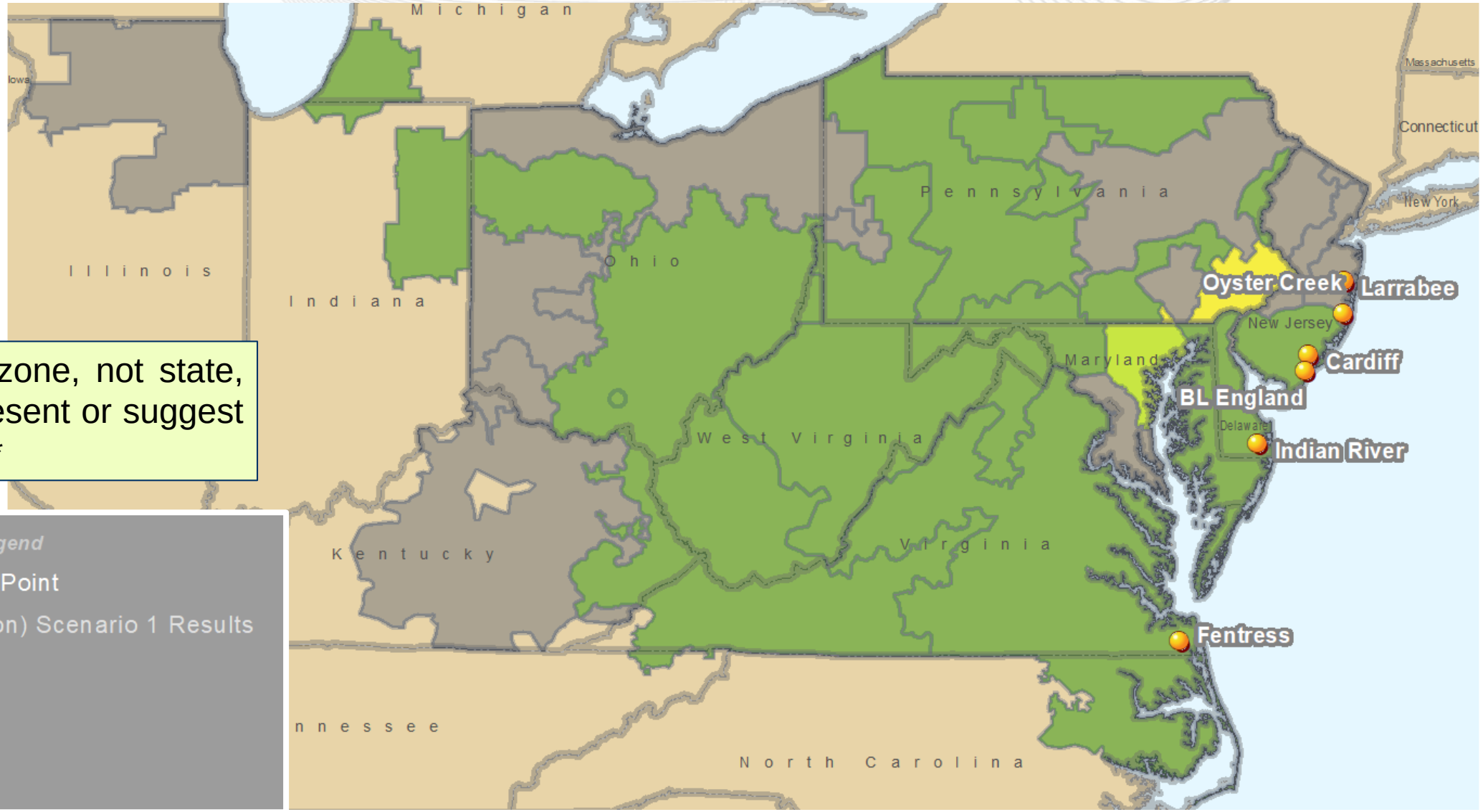
Oyster Creek 230 kV	BL England 138 kV	Larrabee 230 kV	Cardiff 230 kV
816 MW	432 MW	1,200 MW*	600 MW*

Deactivations**	Utility-Scale Solar | Onshore Wind | Storage	Distributed Solar | EV | EE
	State RPS for 2027	2020 PJM Load Forecast Report for 2027

TO Zone	Upgrades (kV) <230	230 & 345	500	Transformer	Upgrade Cost ($M)
AEC	$11.30			$5.34	**$16.64**
AEP	$19.10				**$19.10**
APS	$15.70				**$15.70**
BGE			$173.50		**$173.50**
Dominion		$22.50		$34.00	**$56.50**
DPL	$0.20				**$0.20**
Met-Ed		$5.20			**$5.20**
PECO		$5.40	$255.60	$50.00	**$311.00**
PSEG		$29.50			**$29.50**
Total ($M)	$46.30	$62.60	$429.10	$89.34	**$627.34**

Announced | ** Inputs selected by PJM | ** Deactivations in PJM announced by 10/1/2020 considered in all scenarios*

Scenario 1 – Upgrade Cost Estimates by Zone



Costs are by zone, not state, and do not represent or suggest cost allocation.

Legend

OSW Injection Point

Upgrade Cost ($Million) Scenario 1 Results

- 0
- 1 - 99
- 100 - 199
- 200 - 311

Scenario 2 Results

Scenario 2 – 2035 RPS Target

Offshore Wind Injections: **14,416 MW**

DE & MD

Indian River 230 kV

248 MW | 1,320 MW*

NC & VA

Fentress 500 kV 2,600 MW

Landstown 230 kV 2,600 MW

NJ

Oyster Creek 230 kV, 816 MW

BL England 138 kV, 432 MW

Larrabee 230 kV, 1,200 MW

Deans 500 kV, 3,100 MW

Smithburg 500 kV, 1,200 MW

Cardiff 230 kV, 900 MW

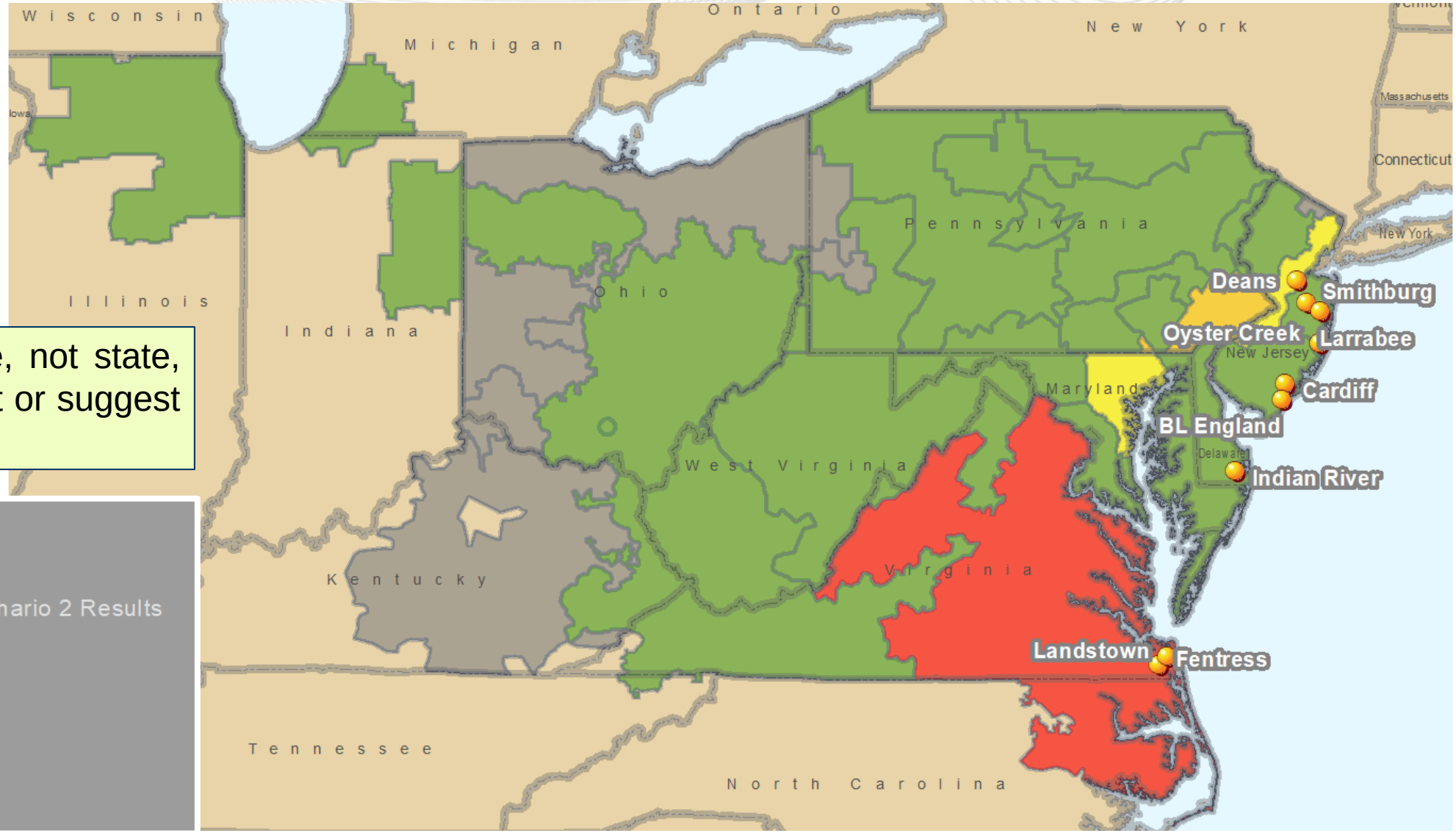
Deactivations**	Utility-Scale Solar | Onshore Wind | Storage	Distributed Solar | EV | EE
& 1,739 MW unannounced	State RPS for 2035	2020 PJM Load Forecast Report for 2035

** Inputs selected by PJM | ** Deactivations in PJM announced by 10/1/2020 considered in all scenarios*

Announced

TO Zone	Upgrades (kV) <230	230 & 345	500	Transformer	Upgrade Cost ($M)
AEC	$11.30	$27.60		$ 11.34	**$50.24**
AEP	$36.50			$9.00	**$45.50**
APS	$37.20				**$37.20**
BGE	$27.60	$95.15	$173.50		**$296.25**
ComEd	$15.10	$38.40			**$53.50**
Dominion	$135.00	$518.10	$ 250.30	$153.00	**$1,056.40**
DPL	$34.90	$18.50			**$53.40**
JCPL	$13.80	$15.90			**$29.70**
Met-Ed	$9.20	$ 5.20			**$14.40**
PECO		$ 75.60	$ 303.50	$50.00	**$429.10**
Penelec				$50.00	**$50.00**
PEPCO		$0.70			**$0.70**
PPL		$12.15			**$12.15**
PSEG		$332.90			**$332.90**
Total ($M)	$ 320.60	$1,140.20	$ 727.30	$ 273.34	**$2,461.44**

Scenario 2 – Upgrade Cost Estimates by Zone



Costs are by zone, not state, and do not represent or suggest cost allocation.

Legend

OSW Injection Point

Upgrade Cost ($Million) Scenario 2 Results

- 0
- 1 - 99
- 100 - 199
- 200 - 399
- 400 - 499
- 500 - 1094

Scenario 3

Scenario #3 was not modeled as a result of pending legislation that was withdrawn.

Scenario 4 Results

Scenario 4 – 2035 RPS Target

Offshore Wind Injections: 17,016 MW

DE & MD

Indian River 230 kV

248 MW | 1,320 MW*

NC & VA

Fentress 500 kV
5,200 MW

Landstown 230 kV
2,600 MW

NJ

Oyster Creek 230 kV, 816 MW

BL England 138 kV, 432 MW

Larrabee 230 kV, 1,200 MW

Deans 500 kV, 3,100 MW

Smithburg 500 kV, 1,200 MW

Cardiff 230 kV, 900 MW

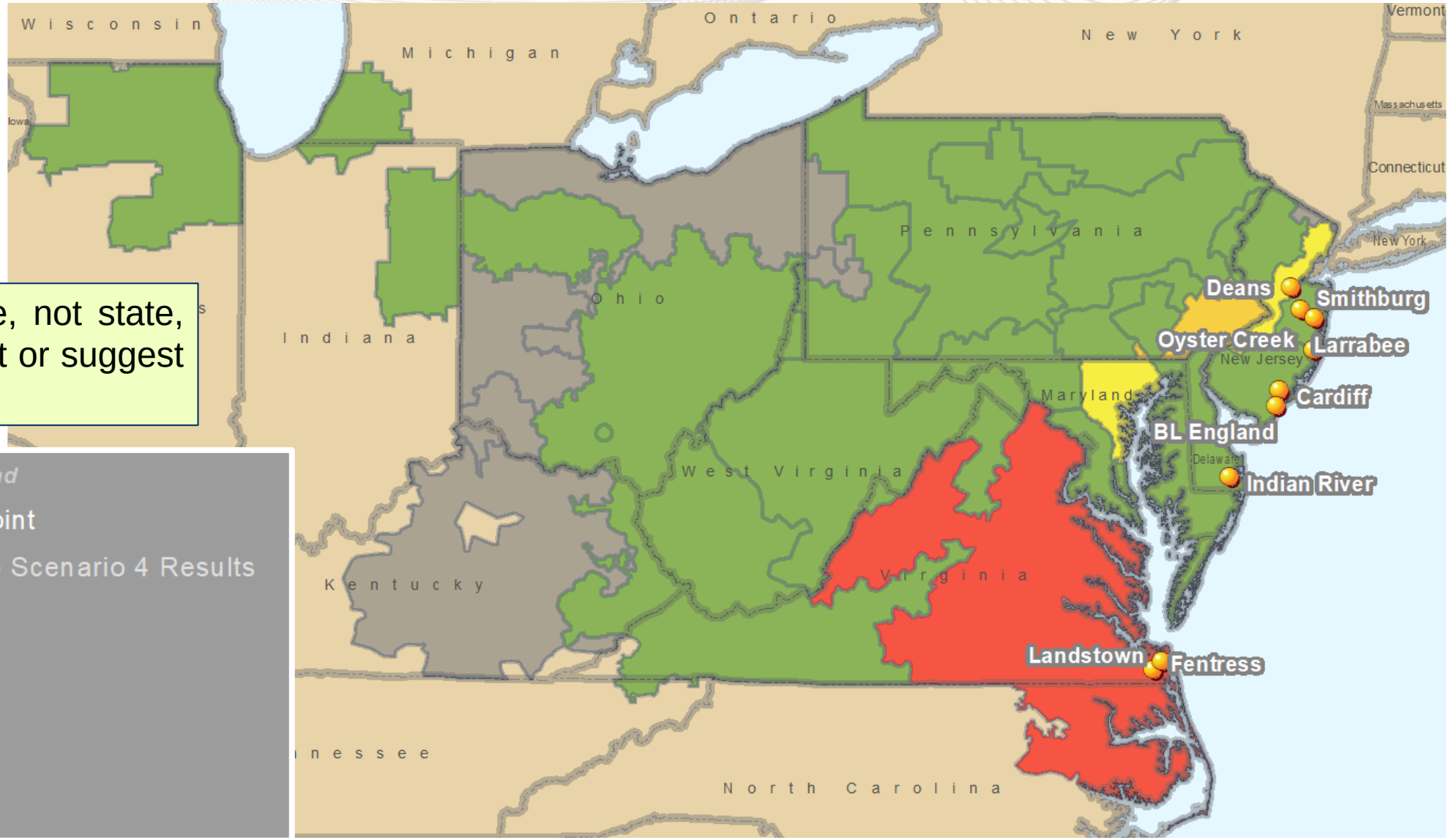
Deactivations**	Utility-Scale Solar | Onshore Wind | Storage	Distributed Solar | EV | EE
& 1,739 MW unannounced	State RPS for 2035	2020 PJM Load Forecast Report for 2035

** Inputs selected by PJM | ** Deactivations in PJM announced by 10/1/2020 considered in all scenarios*

Announced

TO Zone	Upgrades (kV) <230	230 & 345	500	Transformer	Upgrade Cost ($M)
AEC	$11.30	$27.60		$11.34	**$50.24**
AEP	$33.50			$9.00	**$42.50**
APS	$37.20				**$37.20**
BGE	$27.60	$27.25	$173.50		**$228.35**
ComEd	$15.10	$38.40			**$53.50**
Dominion	$135.00	$557.40	$995.30	$191.00	**$1,878.70**
DPL	$35.20	$18.50			**$53.70**
JCPL	$13.80	$15.90			**$29.70**
Met-Ed	$9.20	$5.20			**$14.40**
PECO		$75.60	$303.50	$50.00	**$429.10**
Penelec				$50.00	**$50.00**
PEPCO		$0.70			**$0.70**
PPL		$12.15			**$12.15**
PSEG		$332.90			**$332.90**
Total ($M)	$317.80	$1,111.60	$1,472.30	$311.34	**$3,213.14**

Scenario 4 – Upgrade Cost Estimates by Zone



Costs are by zone, not state, and do not represent or suggest cost allocation.

Legend

OSW Injection Point

Upgrade Cost ($Million) Scenario 4 Results

- 0
- 1 - 99
- 100 - 199
- 200 - 399
- 400 - 499
- 500 - 1916

Scenario 5 Results

Scenario 5 – 2035 RPS Target

Offshore Wind Injections: 14,416 MW

DE & MD

Indian River 230 kV

248 MW | 1,320 MW*

NC & VA

Fentress 500 kV 2,600 MW

Landstown 230 kV 2,600 MW

NJ

Oyster Creek 230 kV, 816 MW

BL England 138 kV, 432 MW

Larrabee 230 kV, 1,200 MW

Deans 500 kV, 3,100 MW

New Freedom 500 kV, 1,200 MW

Cardiff 230 kV, 900 MW

Deactivations**	Utility-Scale Solar | Onshore Wind | Storage	Distributed Solar | EV | EE
& 1,739 MW unannounced	State RPS for 2035	2020 PJM Load Forecast Report for 2035

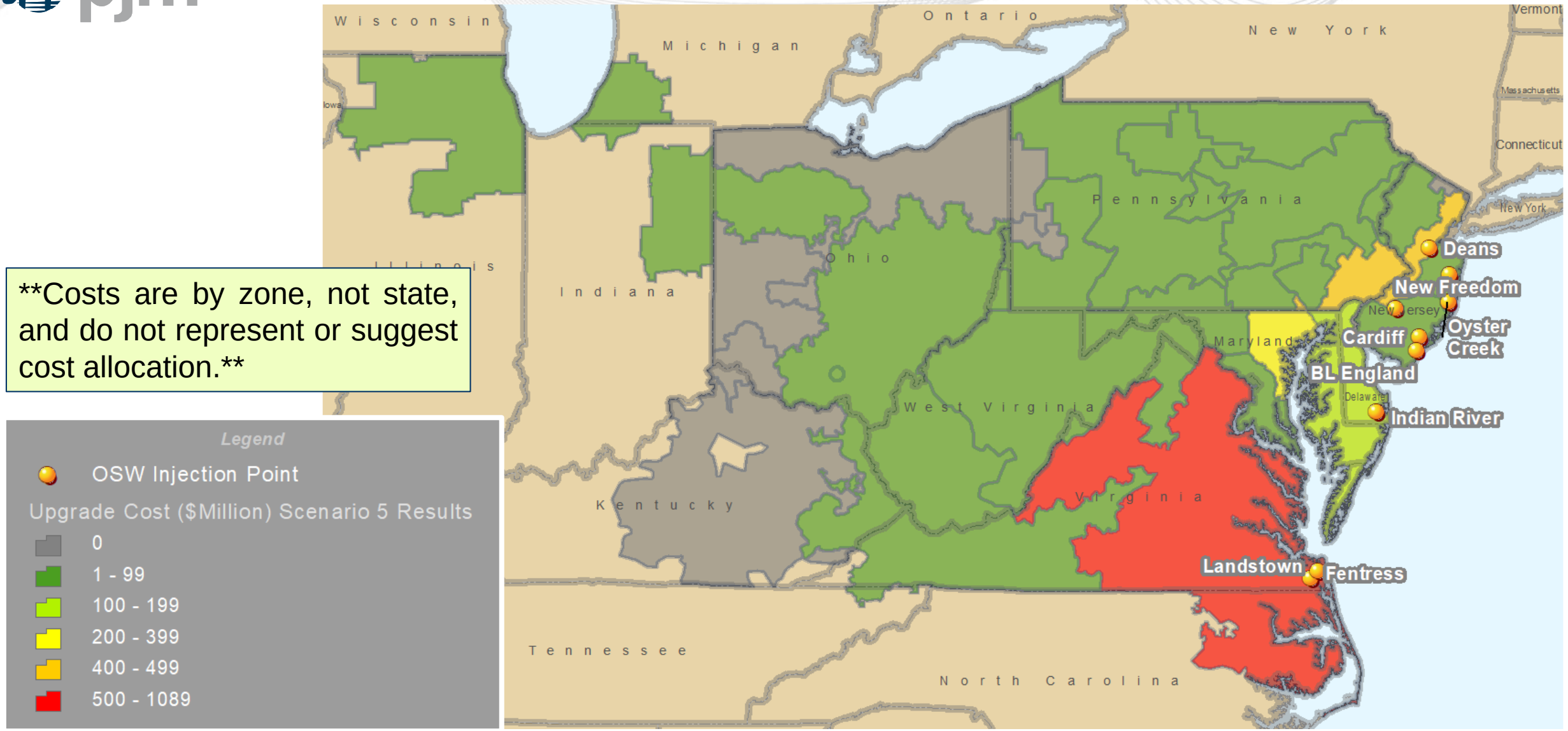
** Inputs selected by PJM | ** Deactivations in PJM announced by 10/1/2020 considered in all scenarios*

Announced

TO Zone	Upgrades (kV) <230	230 & 345	500	Transformer	Upgrade Cost ($M)
AEC	$25.20	$27.60		$11.34	**$64.14**
AEP	$37.80			$9.00	**$46.80**
APS	$43.80				**$43.80**
BGE	$27.60	$37.15	$173.50		**$238.25**
ComEd	$15.10	$38.40			**$53.50**
Dominion	$135.00	$519.60	$250.30	$147.00	**$1,051.90**
DPL	$34.90	$83.50			**$118.40**
JCPL	$16.40	$21.90			**$38.30**
Met-Ed	$9.20	$5.20			**$14.40**
PECO		$75.60	$303.50	$50.00	**$429.10**
Penelec	$0.50			$50.00	**$50.50**
PEPCO		$0.70			**$0.70**
PPL		$12.15			**$12.15**
PSEG		$404.90		$25.00	**$429.90**
Total ($M)	$345.50	$1,226.70	$727.30	$ 292.34	**$2,591.84**

Scenario 5 – Upgrade Cost Estimates by Zone

Costs are by zone, not state, and do not represent or suggest cost allocation.



Scenario 6 Results

Scenario 6 – 2035 RPS Target

Offshore Wind Injections: 12,416 MW

DE & MD

Indian River 230 kV

248 MW | 1,320 MW*

NC & VA

Fentress 500 kV 2,600 MW

Landstown 230 kV 2,600 MW

NJ

Oyster Creek 230 kV, 816 MW

Deans 500 kV, 2,300 MW

BL England 138 kV, 432 MW

Cardiff 230 kV, 900 MW

Larrabee 230 kV, 1,200 MW

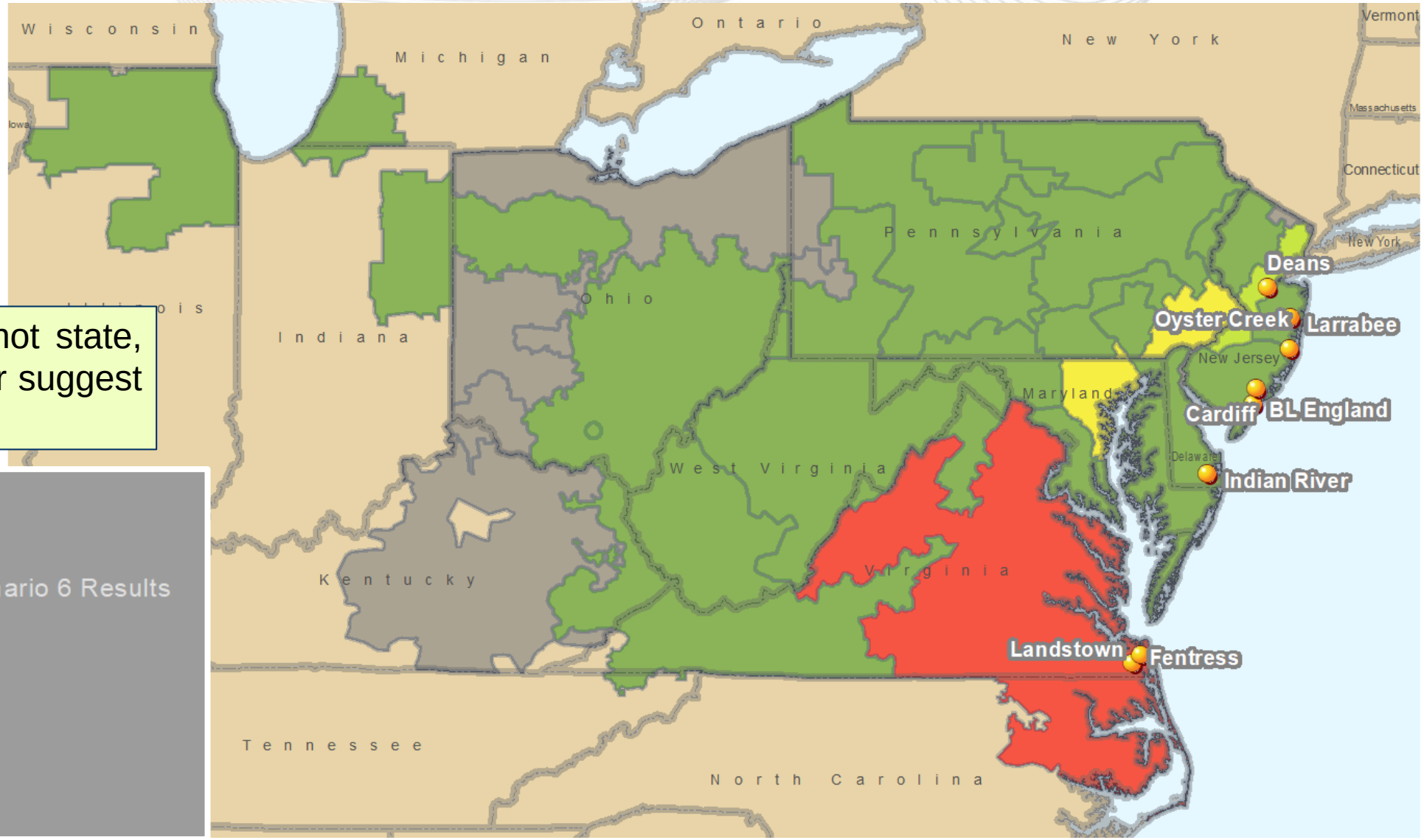
Deactivations**	Utility-Scale Solar | Onshore Wind | Storage	Distributed Solar | EV | EE
& 1,739 MW unannounced	State RPS for 2035	2020 PJM Load Forecast Report for 2035

** Inputs selected by PJM | ** Deactivations in PJM announced by 10/1/2020 considered in all scenarios*

Announced

	Upgrades (kV)				
TO Zone	<230	230 & 345	500	Transformer	Upgrade Cost ($M)
AEC	$25.20	$27.60		$11.34	**$64.14**
AEP	$37.80			$9.00	**$46.80**
APS	$28.00				**$28.00**
BGE	$27.60	$27.25	$173.50		**$228.35**
ComEd	$15.10	$38.40			**$53.50**
Dominion	$135.00	$516.30	$250.30	$153.00	**$1,054.60**
DPL	$34.90	$18.50			**$53.40**
JCPL	$16.40	$10.80			**$27.20**
Met-Ed	$9.20	$5.20			**$14.40**
PECO		$75.60	$255.60	$50.00	**$381.20**
Penelec				$50.00	**$50.00**
PEPCO		$0.70			**$0.70**
PPL		$1.05			**$1.05**
PSEG		$161.00			**$161.00**
Total ($M)	$ 329.20	$882.40	$679.40	$273.34	**$2,164.34**

Scenario 6 – Upgrade Cost Estimates by Zone



Costs are by zone, not state, and do not represent or suggest cost allocation.

Legend

OSW Injection Point

Upgrade Cost ($Million) Scenario 6 Results

- 0
- 1 - 99
- 100 - 199
- 200 - 399
- 400 - 499
- 500 - 1092

Summary

Cost Estimates

- Range from $627.34 million to $3,213.14 million
  - OSW injection totals range 6,416 MW–17,016 MW

Key Conclusions/ Takeaways

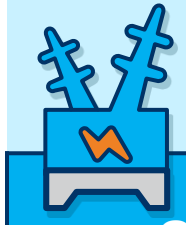
- Costs increase significantly between 2027 and 2035 scenarios, commensurate with RPS requirements
  - RPS targets modeled to be met in all scenarios
- Network upgrades and associated costs identified in all scenarios
  - High-level analysis, non-inclusive of all PJM Tariff facilities, neighboring affected systems
- Market efficiency analysis for Scenario 1 demonstrates decreased gross load payments, especially for coastal states, among other benefits
- Phase 1 results demonstrate system impacts, opportunities to identify possible regional solutions
- Considerations of timeline and constructability

Appendix – Modeled Renewable Generation to Meet RPS Targets

State	Year	Offshore Wind (MW)	Onshore Wind (MW)	Solar (MW)	Storage (MW)
NJ	2027	2,900	-	7,111	1,475
	2035	7,500	-	11,322	2,875
MD	2027	768	210	5,002	-
	2035	1,568	210	5,602	-
DC	2027	-	-	343	-
	2035	-	-	462	-
DE	2027	-	-	468	-
	2035	-	-	595	-
VA	2027	2,600	130	6,270	280
	2035	5,200	130	16,570	3,100
NC	2027	-	600	1,117	-
	2035	-	600	1,153	-
PA	2035	-	1,585	2,185	58
IL		-	7,329	2,406	1,080
OH		18	1,742	3,938	24
MI		-	-	356	-
IN		-	2,325	275	-
Rest of PJM* (KY, TN, WV)		-	609	713	54

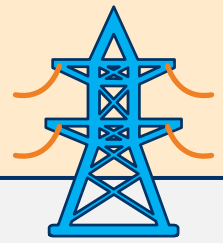
** Non-RPS renewable buildout*

Appendix - Cost Estimates



Cost Estimates for New Transformers

Cost Estimate ($M per unit)	
138 kV High Side	$4
230 kV High Side	$6
345 kV High Side	$9
500 kV High Side	$25
765 kV High Side	$45



Cost Estimates for Transmission Line Upgrades

230 kV Cable			$15 ($M per mile)	
Upgrades	**Cost Estimate ($M per mile)**			
	Reconductor	Loadings	Rebuild	Loadings
115 kV & 138 kV	$0.8	≤ 400 MVA	$1.2	> 400 MVA
230 kV	$1.2	≤ 1,200 MVA	$1.8	> 1200 MVA
345 kV	$2.0	≤ 1,800 MVA	$3.0	> 1,800 MVA
500 kV	$5.5	≤ 4,000 MVA	$8.0	> 4,000 MVA
765 kV	$8.0	≤ 6,000 MVA	$12.0	> 6,000 MVA

Appendix - Market Efficiency Example Assumptions (Scenario 1)

2025 Base Case	• Market assumptions based on the 2025 PJM Market Efficiency Base Case. • Generation and transmission consistent with the 2025 Base Case used to create the models for the Scenario 1 reliability analysis.
2025 RPS Case	• Additional solar, wind, energy storage generation to reach the RPS standards outlined for Scenario 1. • Transmission upgrades identified in the reliability analysis of Scenario 1 have been applied to the RPS case's topology.

Economic analysis is based off of a comparison of the 2025 RPS case with the 2025 Base Case.

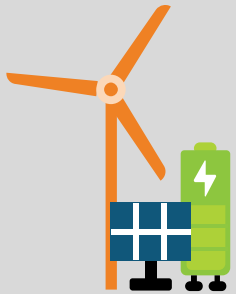
Appendix - Market Efficiency Example Conclusions (Scenario 1)

Congestion Relief

- No new significant simulated congestion after reliability transmission upgrades were applied to the case.
- RPS MW injections help decrease west to east simulated congestion.
- Exports to MISO increase.

Decrease in CO_2 Emissions

- CO_2, NO_X, and SO_2 emissions decrease across PJM's footprint.
- Higher percent emissions decreases in coastal states.



Decrease in Renewable Generation Curtailments

- Wind curtailment across PJM footprint decreases due to reliability transmission upgrades.
- Slight solar curtailment still remains in MD and VA due to RPS solar injections.
- RPS generation is displacing fossil fuel generation across PJM footprint.

Decrease in Gross Load Payments

- Largest decreases in gross load payments are in DC, DE, MD, NJ, NC, PA and VA.
- Slight decreases in gross load payments across remaining PJM states.
- Similar patterns for LMP changes.

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