PJM Clean Power Plan Modeling
Preliminary Phase 1 Long-Term Economic Compliance Analysis Results

May 6, 2016

PJM's Clean Power Plan Modeling

What it is

Robust modeling representation of potential system futures driven by policy, regulatory and market drivers

What isn't it

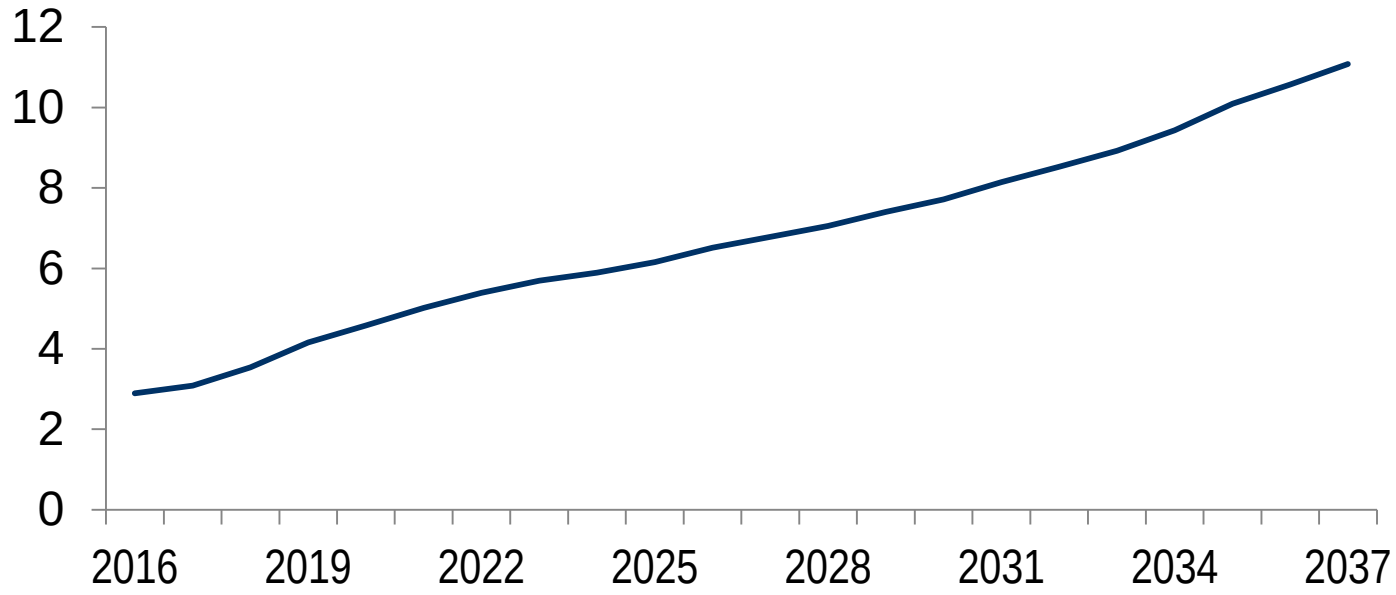
- An economic forecast of expected future outcomes
- A representation of all the considerations resource owners may make in investing in new assets or retiring existing assets

Key Assumptions

Reference Model	Represents the extension of Production and Investment Tax Credit, but no Renewable Portfolio Standard, and a **future without the Clean Power Plan**
Sensitivities	
Reduce Energy Efficiency Emission Rate Credits by 50%	Applied to Trade-Ready Rate Scenario

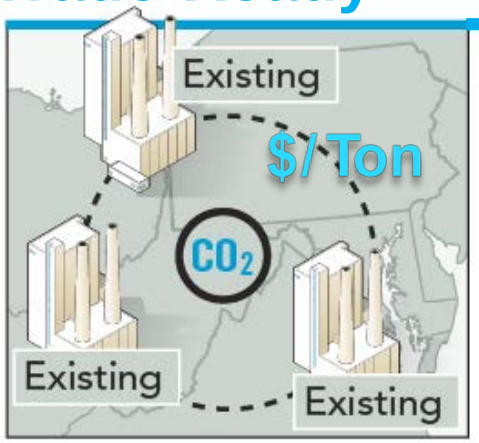
Key Inputs	Description
Inflation	2.25%
Effective Tax Rate	40%
Weighted Average Cost of Capital	8%
Study Horizon	2018 to 2037

Henry Hub Natural Gas Price Forecast ($/mmbtu)



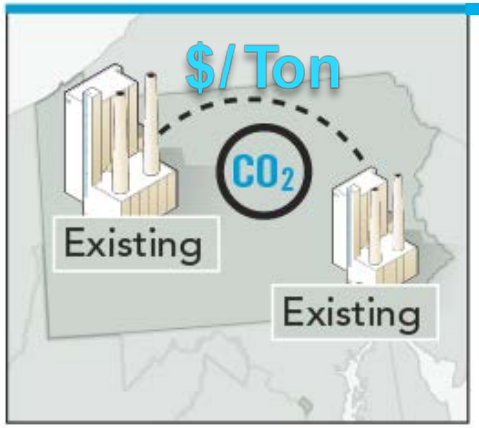
Mass-Based Compliance Pathway Scenarios

Trade-Ready



Single CO_2 limit applied to the PJM region for 111(d) existing resources

State Mass



Each state applies a CO_2 limit covering all 111(d) existing resources

New Source Complement (NSC)

Single CO_2 limit applied to the PJM region for 111(d) existing and 111(b) new sources

State Mass New Source Complement

Each state applies a CO_2 limit covering all 111(d) existing resources and 111(b) new sources

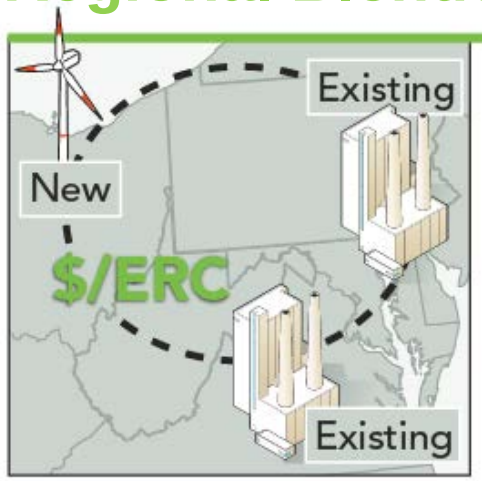
[1] Proposed Federal Plan for the Clean Power Plan (PDF) - http://www.gpo.gov/fdsys/pkg/FR-2015-10-23/pdf/2015-22848.pdf

Rate-Based Compliance Pathway Scenarios

Trade-Ready Rate

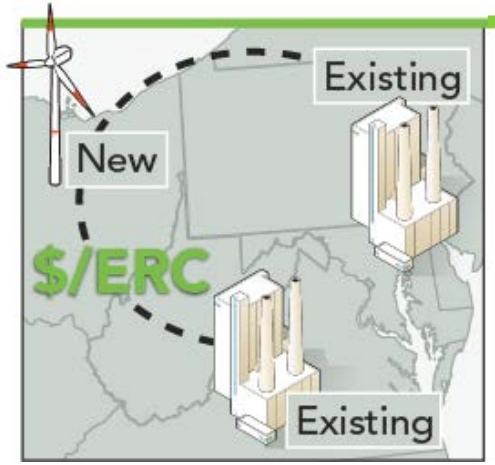
Emissions performance measured against the sub-category CO_2 emission rate targets for combined cycle and steam turbine resources

Regional Blended Rate



Emissions performance measured against a weighted average of PJM states' CO_2 emissions rates

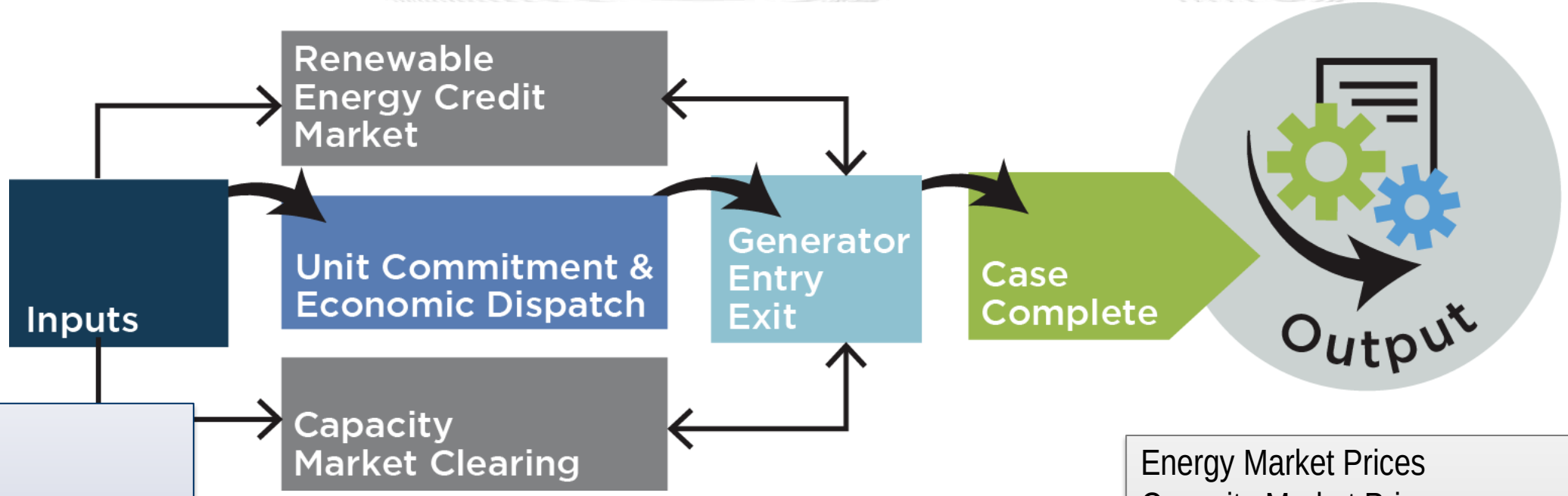
State Blended Rate



Emissions performance measured against the state CO_2 emissions rate target

[1] Proposed Federal Plan for the Clean Power Plan (PDF) - http://www.gpo.gov/fdsys/pkg/FR-2015-10-23/pdf/2015-22848.pdf

Compliance Analytics Diagram



Load Forecast
Fuel Prices
Unit Operational Constraints
Emissions Constraints
Transmission Constraints
Fuel Supply Limitations
Capacity Market Bids
Renewable Portfolio Standards
Demand Response

Energy Market Prices
Capacity Market Prices
Emissions Market Prices
Resource Adequacy Evaluation
Ancillary Service Market Prices
Renewable Energy Credit Prices
Transmission Constrained Areas
Fuel Constrained Areas
New Build Capital Costs

Executive Summary

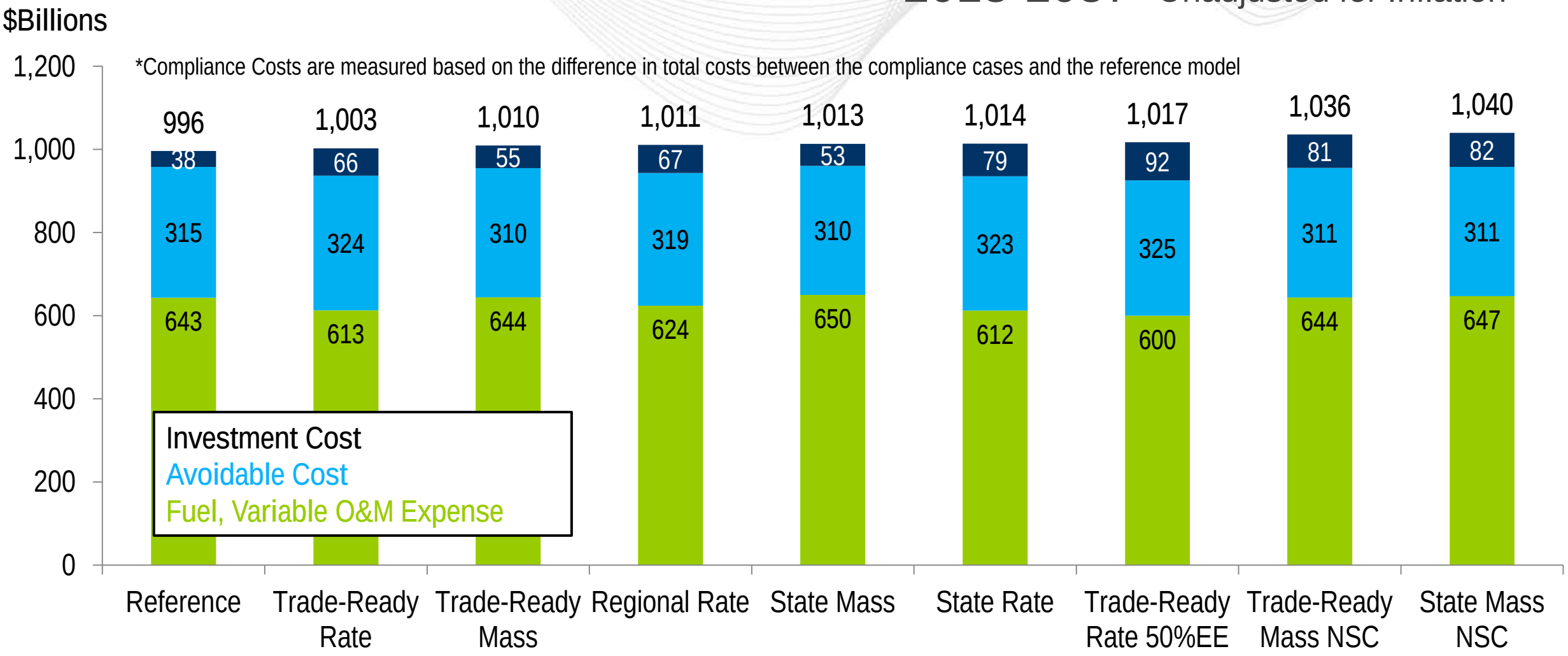
- Trade-ready/regional compliance leads to lower compliance costs.
- Mass-based compliance provides more certainty in emissions levels than rate-based.
- Rate-based compliance can lead to fewer retirements than mass-based compliance but is sensitive to the amount of credits created for zero-emitting resources
- Rate-based compliance reduces wholesale energy market prices relative to mass-based compliance which can negatively impact zero-emitting resources.

Because of PJM's regional economic operations...

- Comparable resources in neighboring states can be dispatched independent of the chosen compliance pathway.
- Interstate or intrastate trading of emissions allowances and credits affects wholesale prices only when they change the marginal resource in energy or capacity markets.

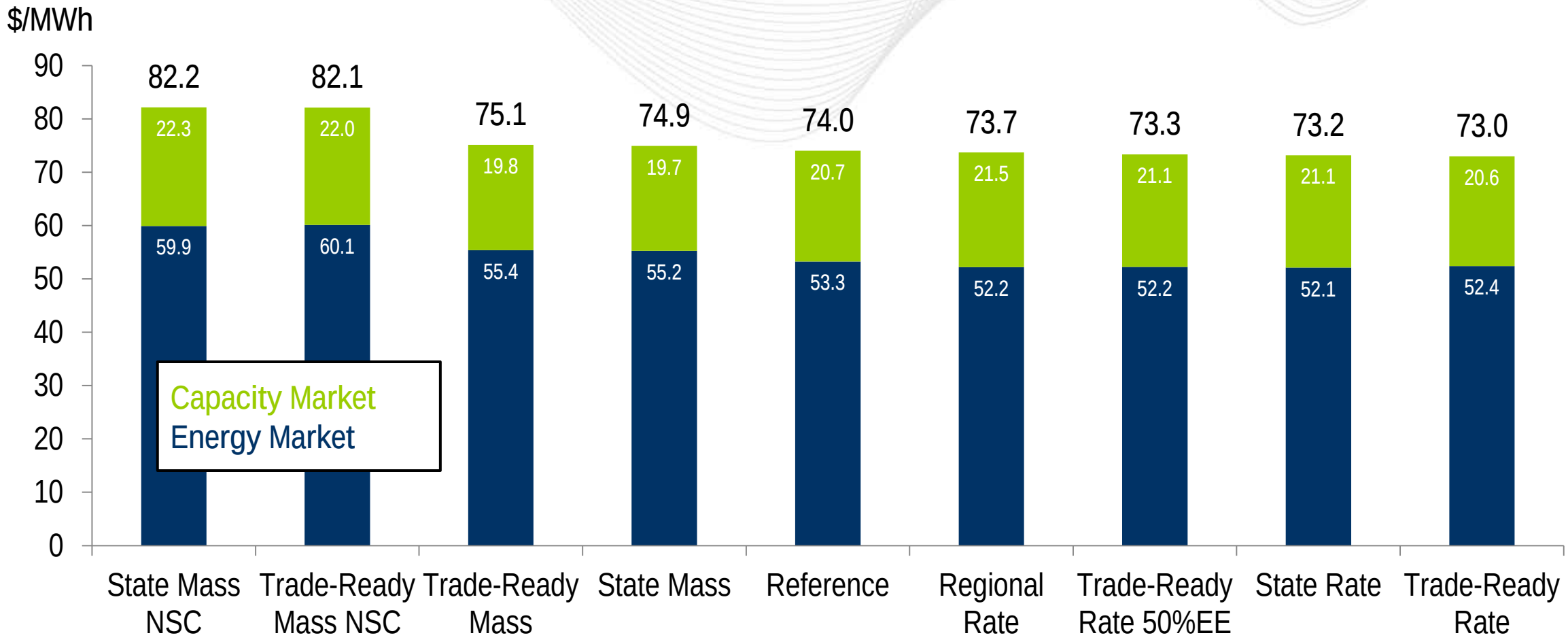
Market and Investment Costs

Generator Production, Avoidable and Investment Costs 2018-2037 *Unadjusted for Inflation

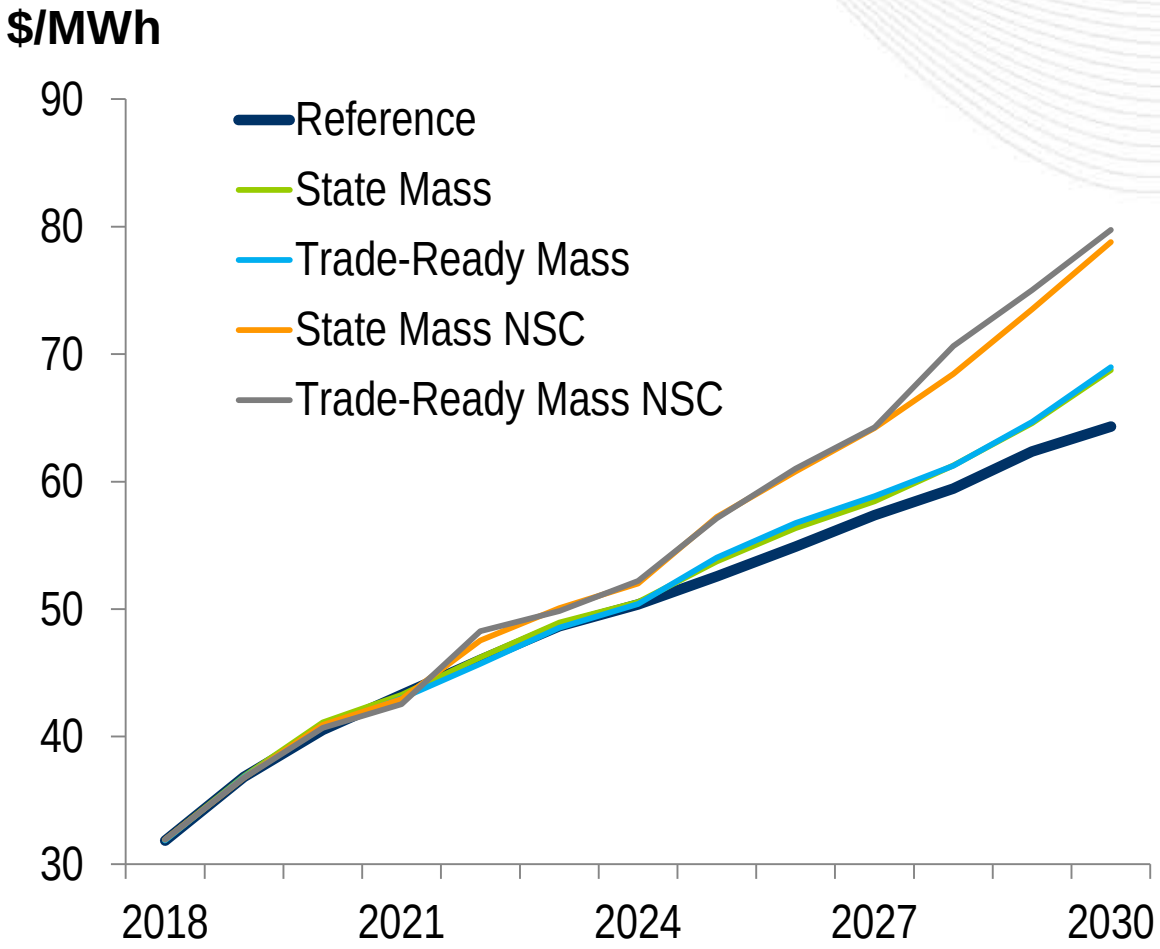


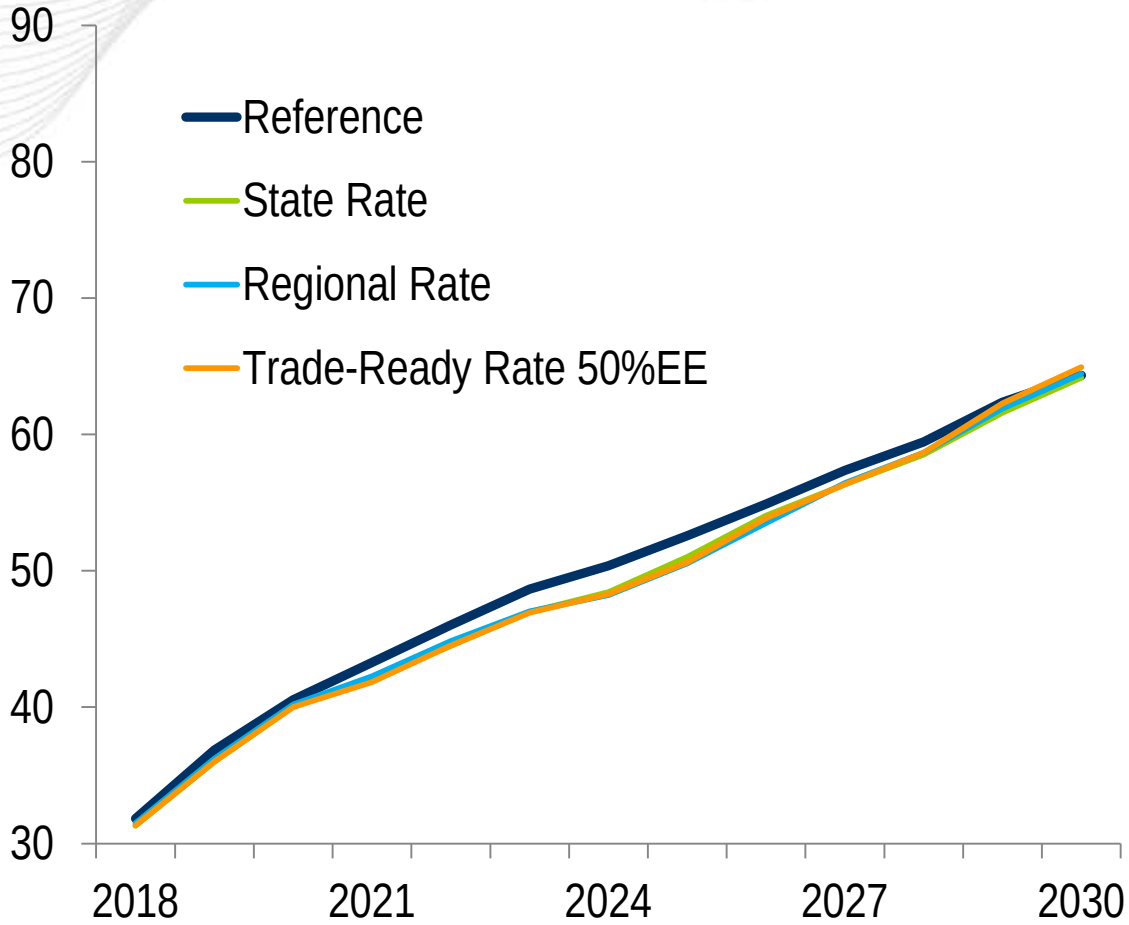
Avoidable cost shown does not capture non-dispatchable existing resources or small (< 25 MW) dis-patchable resources.

Levelized Energy and Capacity Market Costs
Study Horizon: 2018-2037



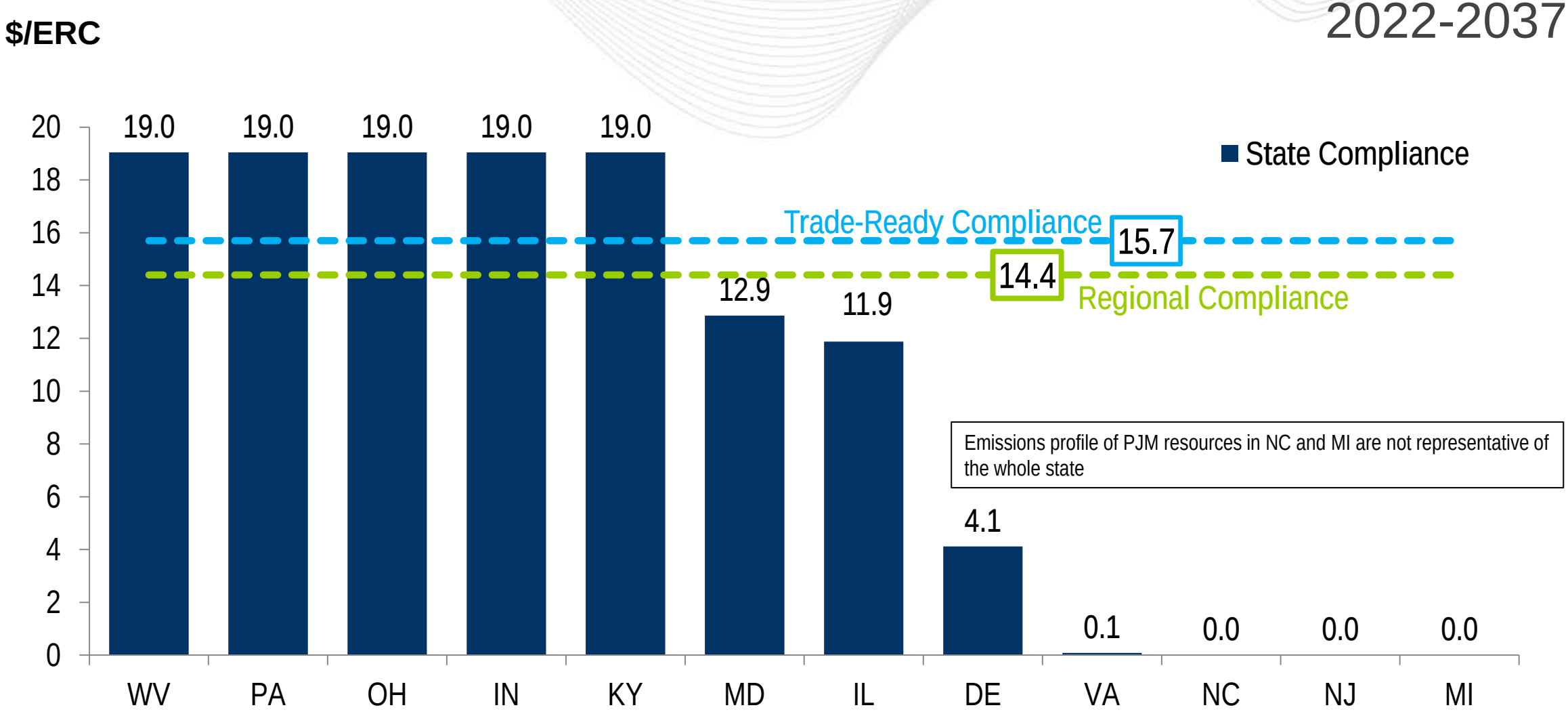
PJM Load-Weighted Energy Market Price



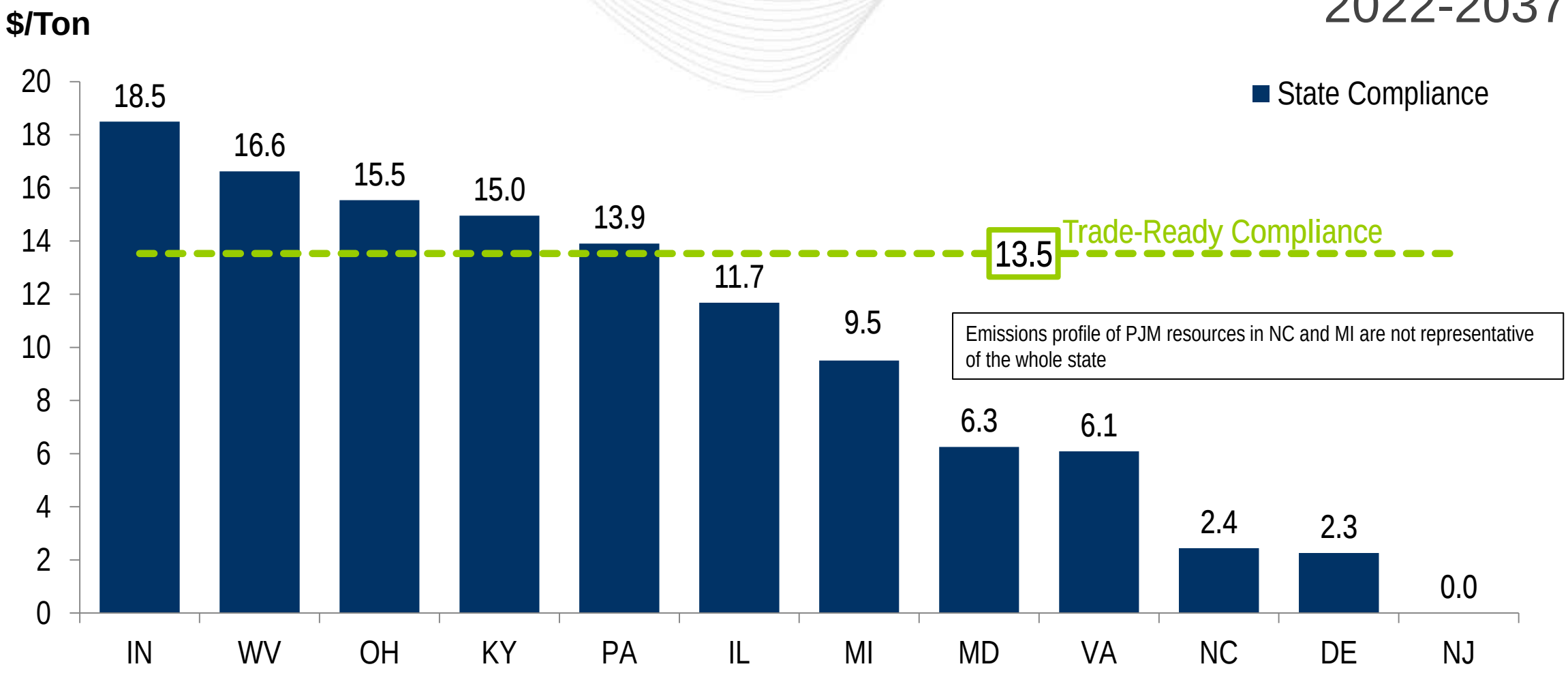


CO_2 Emissions Markets

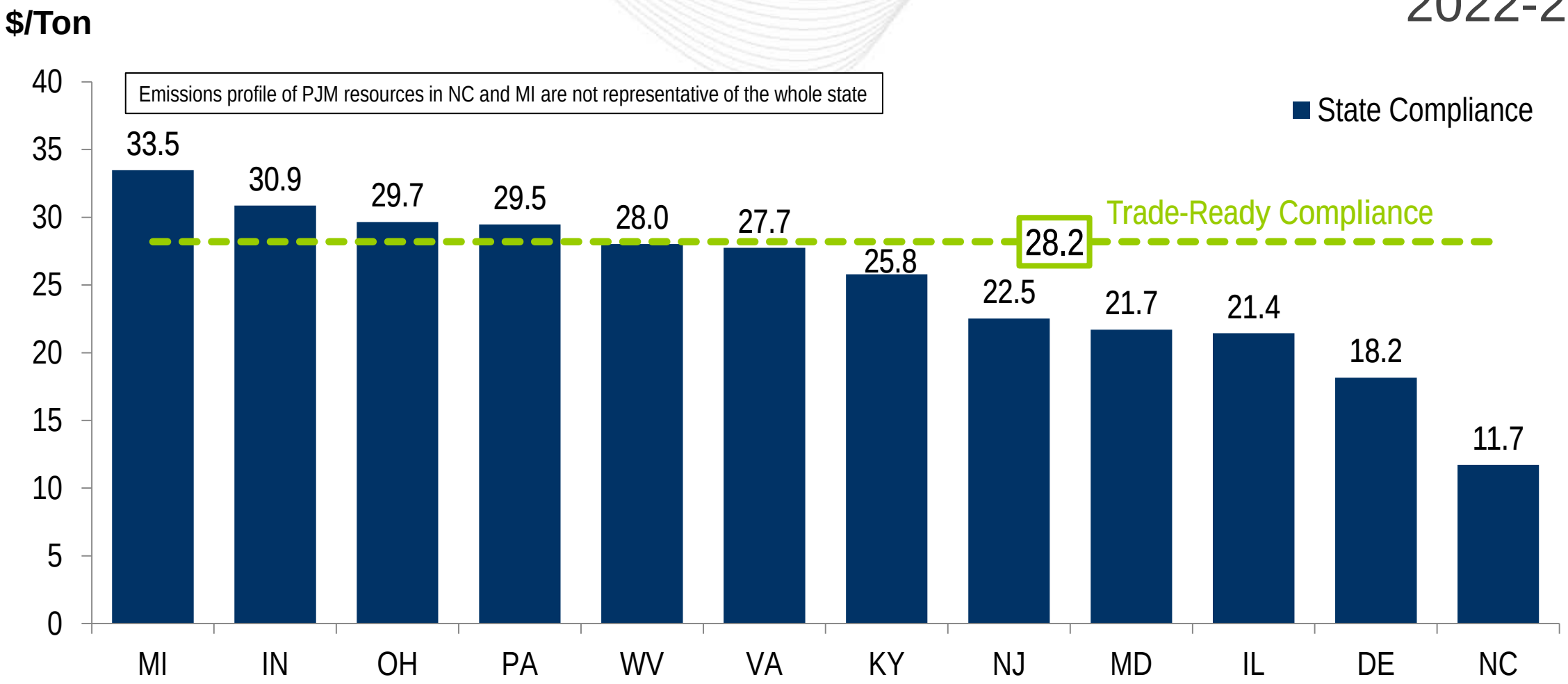
Rate-Based Compliance Pathways
Average Emission Rate Credit Prices for PJM resources 2022-2037



Mass-Based Existing Source Compliance Pathways
Average Allowance Prices for PJM resources
2022-2037

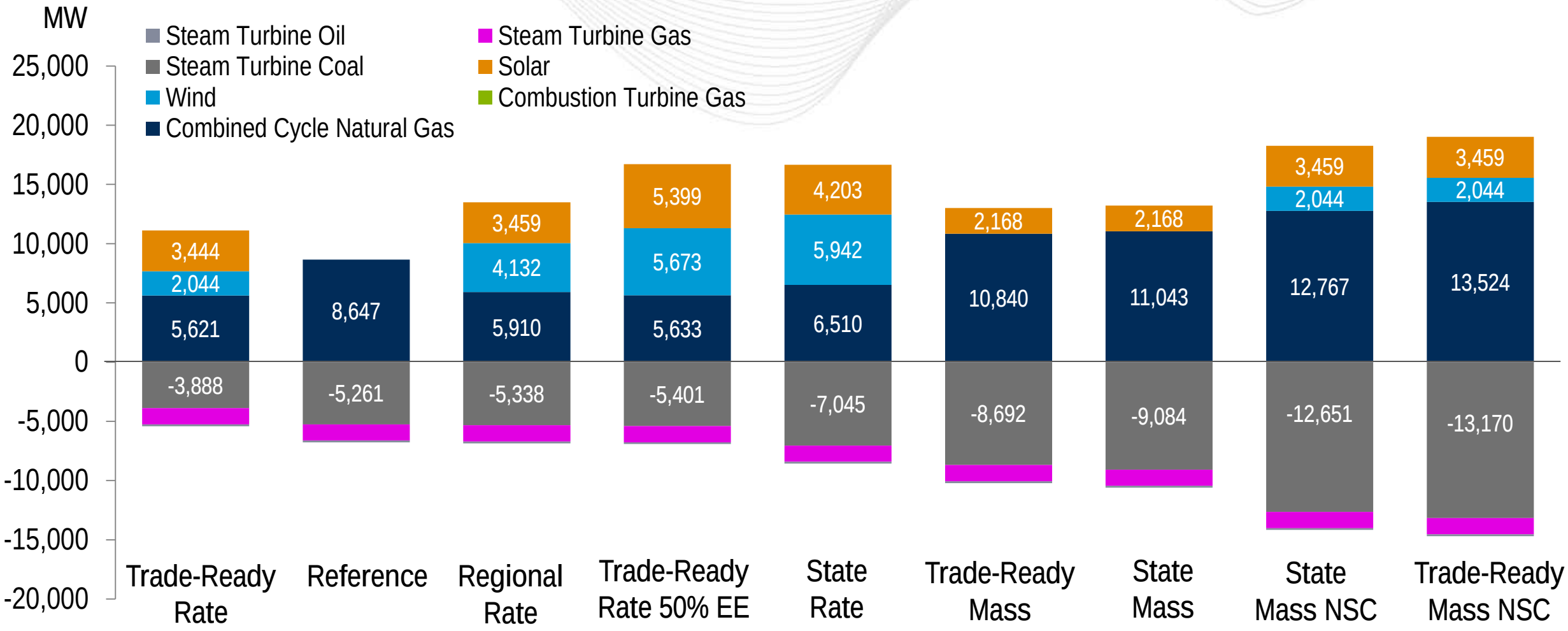


Mass-Based Existing and New Source Compliance Pathways Average Allowance Prices for PJM resources 2022-2037



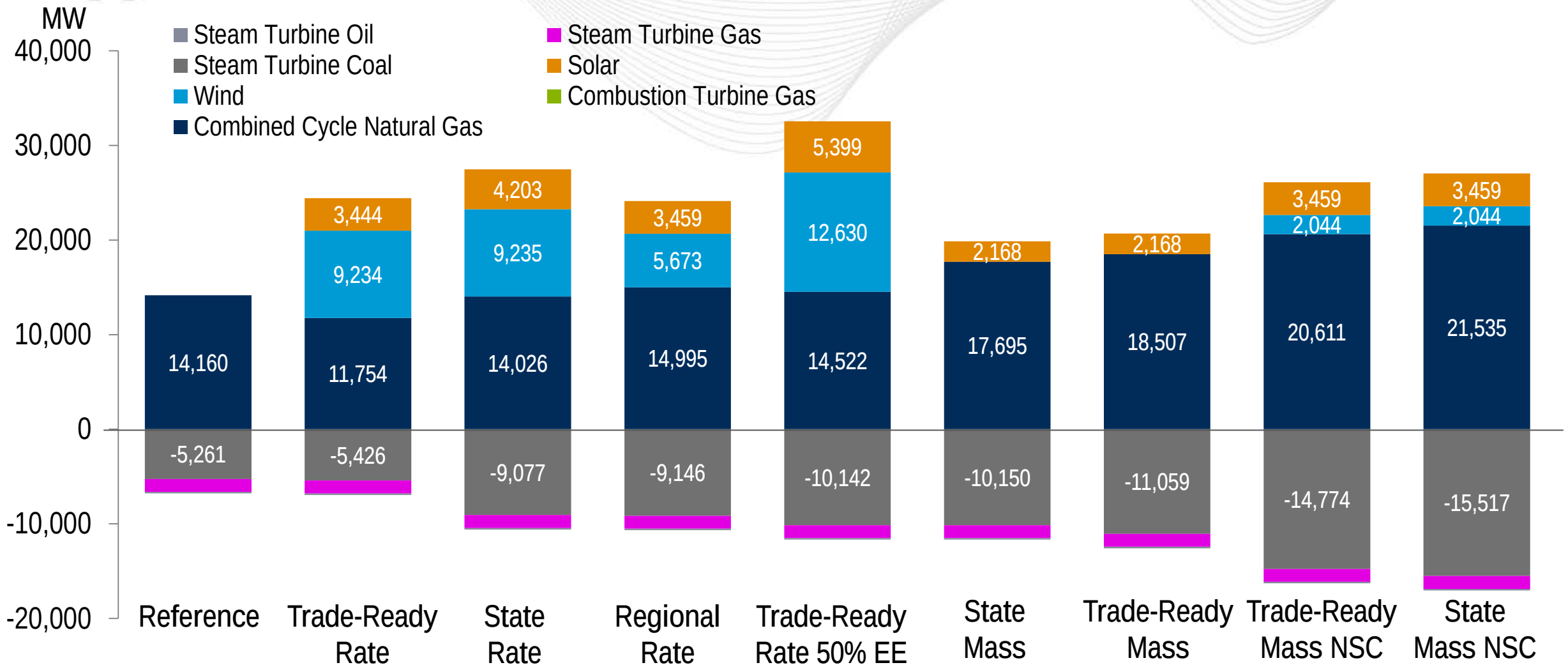
Generating Unit Entry and Exit

Economic Generation Entry/Exit by 2025



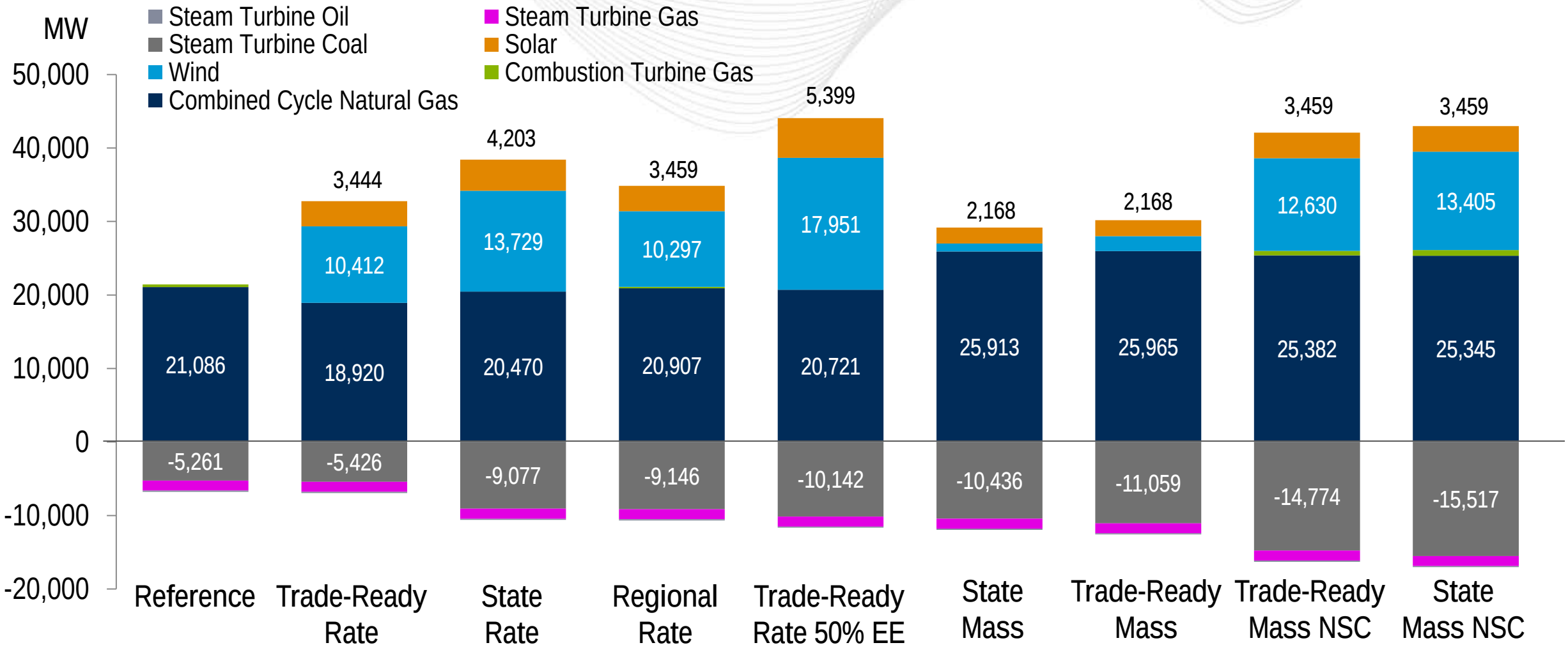
Note: The model represents levelized going forward costs, but does not attempt to capture additional capital investments for coal or nuclear units which can affect going-forward decisions at various times.

Economic Generation Entry/Exit by 2030



Note: The model represents levelized going forward costs, but does not attempt to capture additional life extension costs for coal or nuclear units.

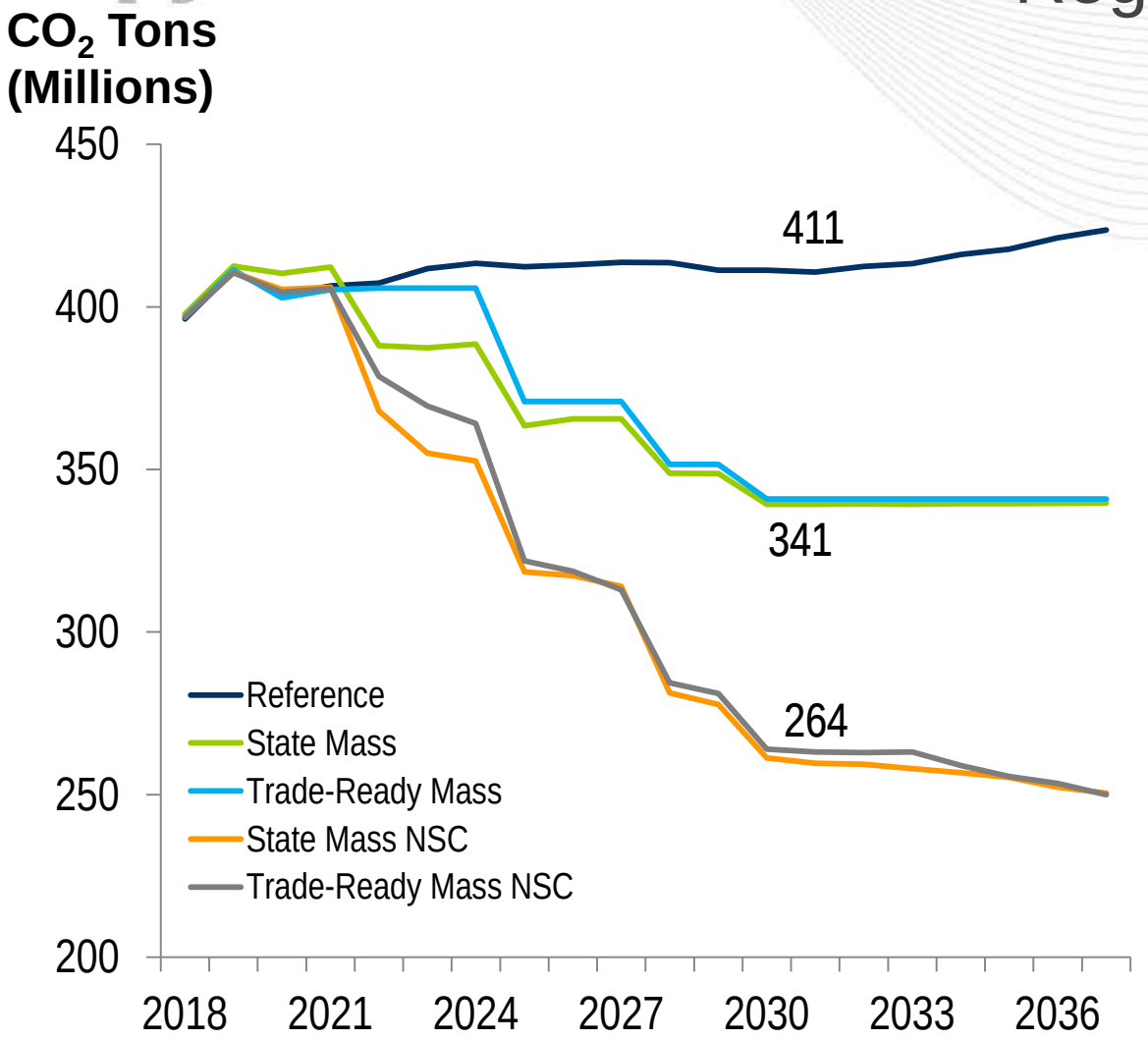
Economic Generation Entry/Exit 2018-2037

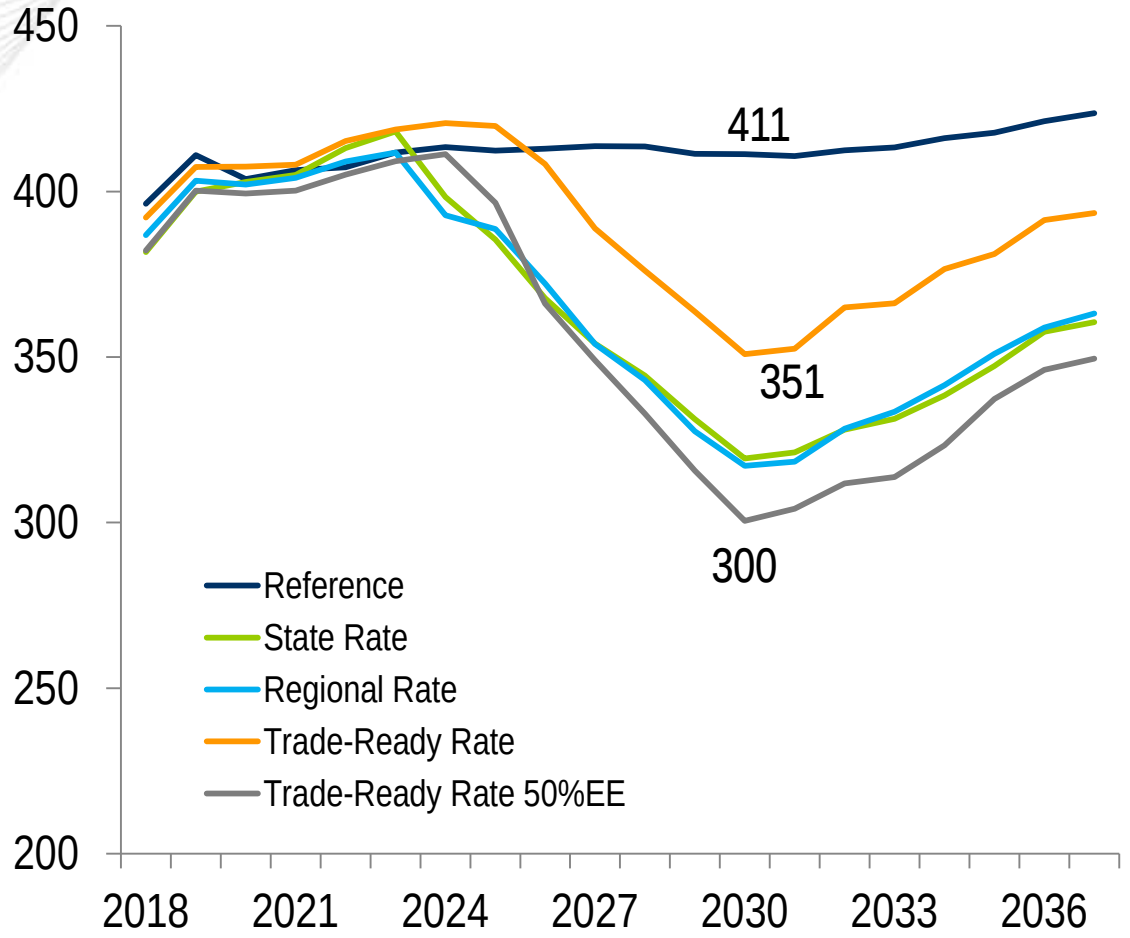


Note: The model represents levelized going forward costs, but does not attempt to capture additional capital investments for coal or nuclear units which can affect going-forward decisions at various times.

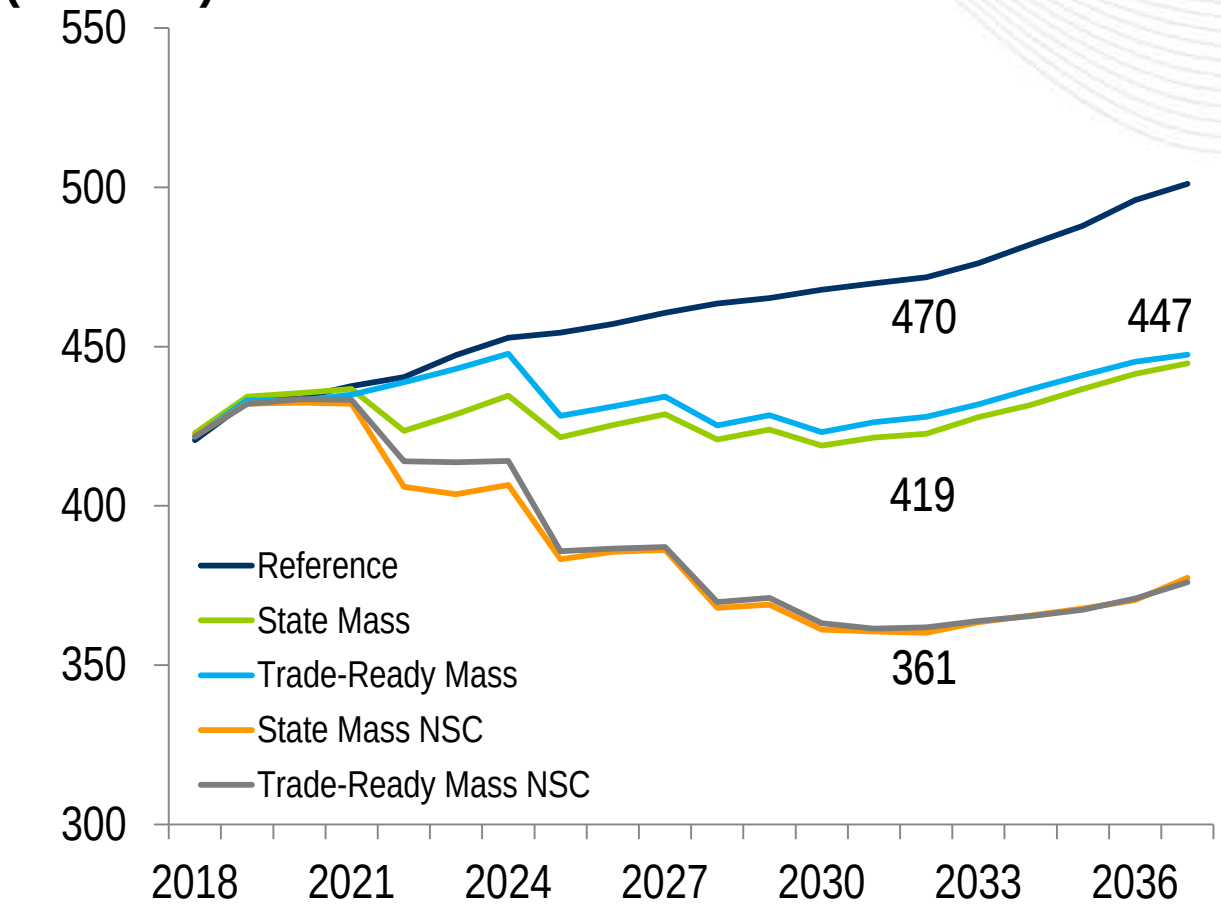
PJM Region CO_2 Emissions

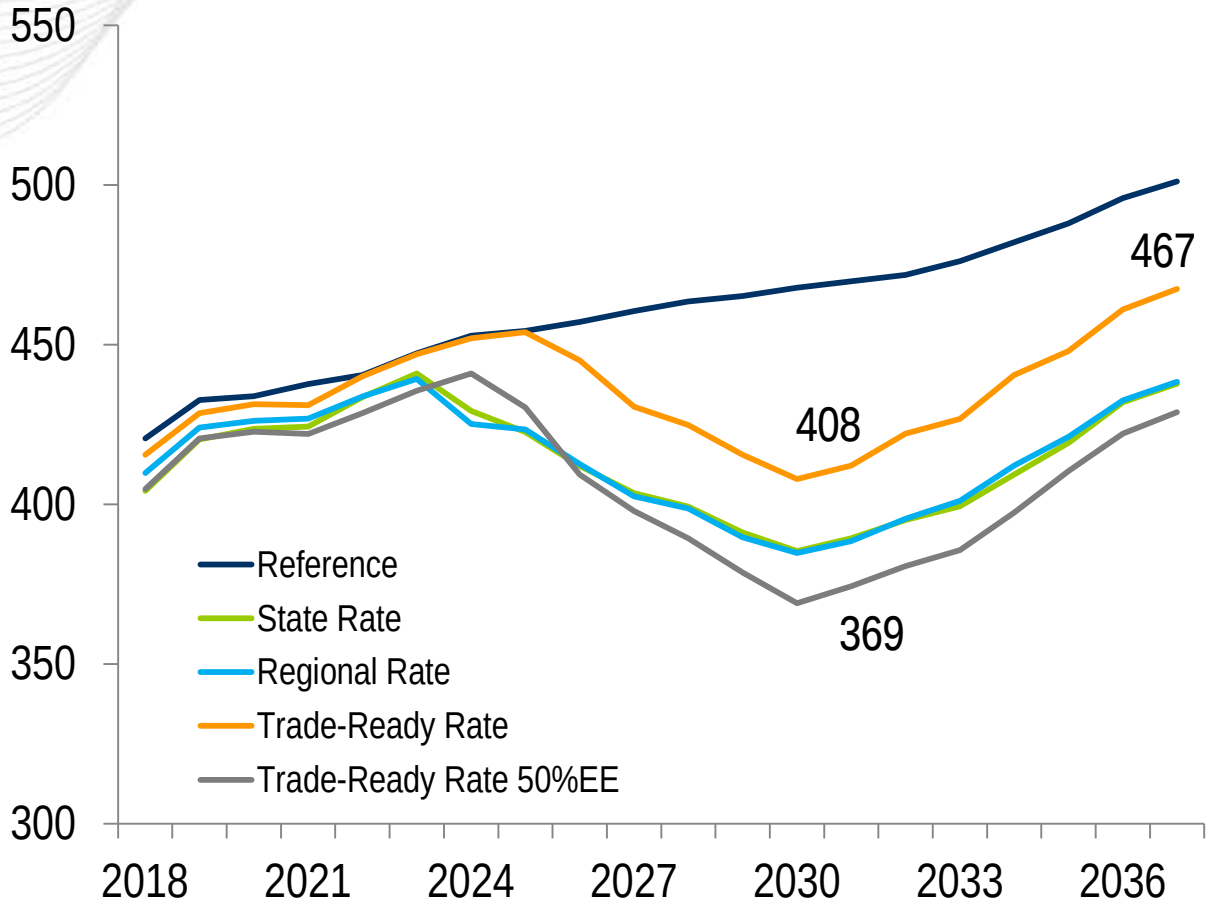
CO_2 Emissions from PJM sources Regulated under the Clean Power Plan



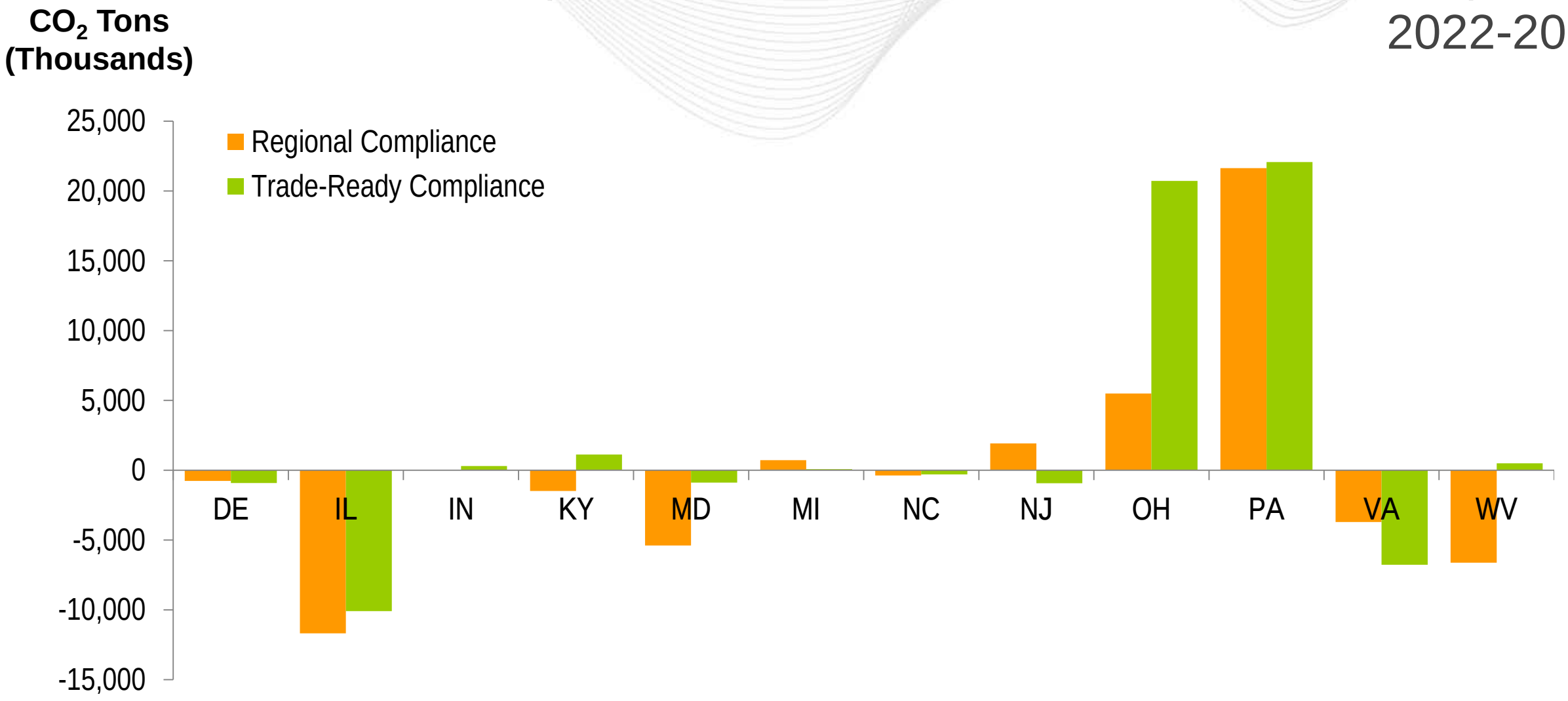


CO_2 Emissions from All PJM sources under the Clean Power Plan

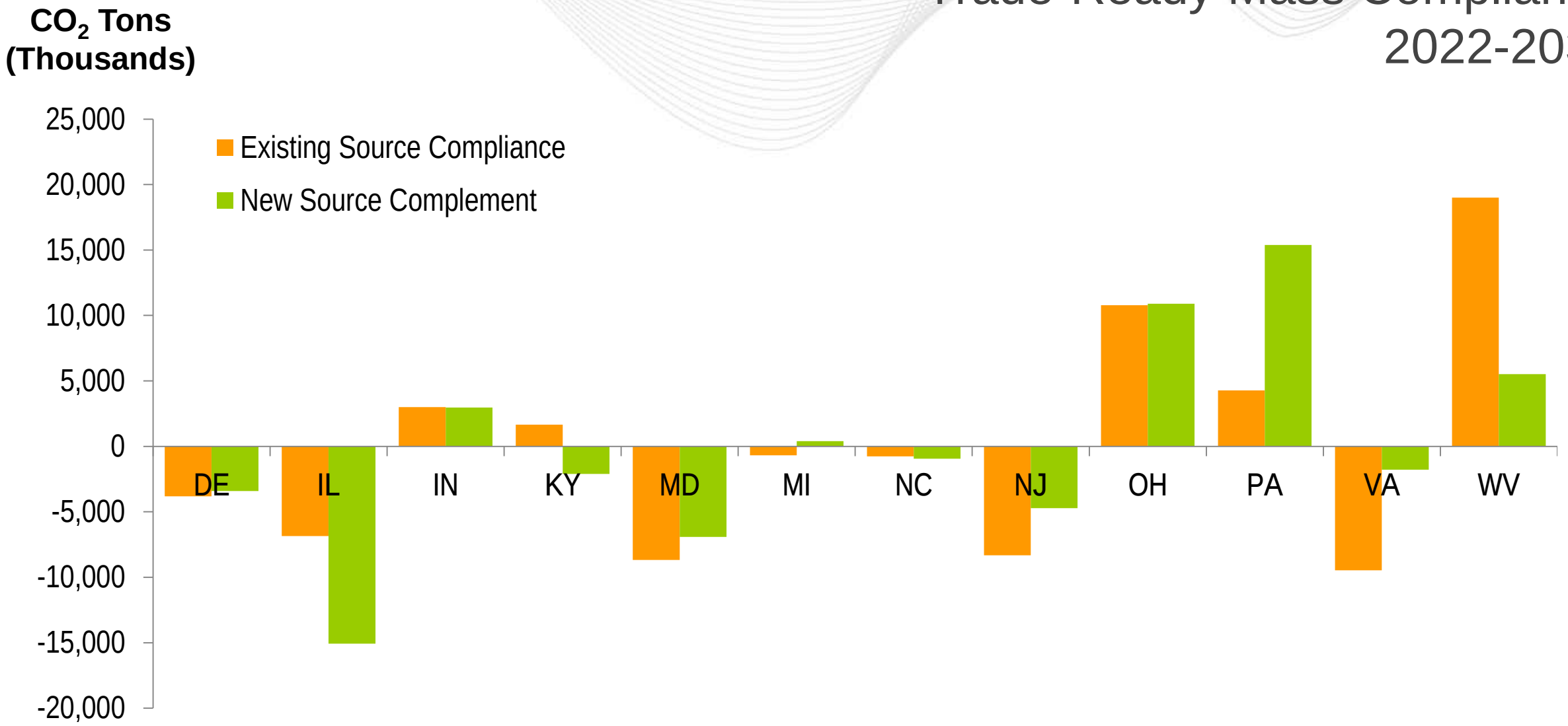




Average Differences in CO_2 Emissions for Multi-state Compliance versus Intrastate Rate-Based Compliance 2022-2037



Average Annual CO_2 Emissions above the State Cap under Trade-Ready Mass Compliance 2022-2037



Key Observations

Due to Trade-Ready/Regional Compliance...

- Overall compliance costs is lower
- Emissions reductions are able to come from the least efficient (fuel and O&M cost) and/or highest emitting resources in PJM.
- Distribution of generator retirements across the footprint changes but not necessarily the level of retirements.
- Coal-dominant states can lower their costs of buying allowances and preserve useful life of assets

Due to regional economic dispatch…

- PJM can dispatch comparable resources in neighboring states independent of the compliance pathway selected by PJM states.
- Interstate or intrastate trading of emissions allowances affects wholesale prices only when they change the marginal resource in energy or capacity markets.

Provided distributed resources and energy efficiency embedded in the load forecast show up and are accounted for through state measurement and verification programs…

- Participants within PJM are able to avoid additional investments in new resources to generate emission rate credits and/or reduce emissions.
- Emissions can rebound under rate-based compliance provided these resources show up and are accounted for through state measurement and verification programs.

Due to regulating new 111(b) resources under the new source complement…

- CO_2 emissions are reduced more than any other compliance pathway.
- Wholesale electric costs increase relative to other compliance methods.
- Emissions compliance costs increase, which drives more retirements but also new entry.

Due to the Investment and Production Tax Credits…

- Renewables can be developed economically much earlier in the study horizon.
- Rate-based compliance appears cheaper than it otherwise would and emissions reductions can be delayed.

Due to a direct payment through emissions rate credit value under rate-based compliance…

- Renewables become a more attractive investment than natural gas combined cycles for compliance.
- Less natural gas combined cycles enter the market, which reduces the level of competition between coal and gas resources.

Due to the capacity market revenues…

- Resources are able to enter the market economically to maintain resource adequacy throughout the study horizon.

Due to the ability of renewable resources located in state A to sell emissions rate credits to a resource in state B…

- Resources in rate-based states with limited renewable potential can comply with similar costs as resources in states with greater local renewable potential.
- States with similar fuel mix and demand for emission rate credits face similar compliance cost.

Due to the sub-category rate target for coal resources being higher than the blended rate targets…

- There is less demand for emission rate credits during the early part of the compliance period.
- Emissions rebound effects are much more significant when the amount of energy efficiency and renewable resources increase.
- There are fewer retirements under trade-ready rate compliance than other compliance pathways.

Next Steps

- June 2016 – Complete transmission congestion analysis and Compliance Pathways Economic Assessment Report
- Q3/Q4
  - Perform economic and reliability sensitivities
  - Perform coordinated analysis with MISO

Appendix

Definitions and Acronyms

- All sources – All CO_2 emitting sources reporting to EPA's continuous emissions monitoring system
- Emission Rate Credit (ERC) – mechanism for trading in rate-based market
- Emissions allowance – mechanism for trading in mass-based market
- 111(d) or Existing sources – Steam turbine coal/oil/gas, combined cycle gas built or under-construction by 2012
- New Source Complement (NSC) – Existing sources and new sources covered under the new source performance standard (111b) rules

Clean Power Plan Analysis
2014 Versus 2016 Analysis

	2014 Analysis	2016 Analysis
Simulation Tool	ABB Promod IV	Plexos by Energy Exemplar
Energy Market	Chronological simulation of discrete years (SCED)	Chronological and load duration curve based simulation
Entry/Exit	None (Unit at-risk analysis performed in post-processing)	20-year optimized economic entry/exit based on simulated energy and capacity market revenues
Capacity Market	None	20-year BRA clearing for RTO within simulation
Reserves	RTO operating reserves	RTO operating reserves
Renewable Portfolio Standard (RPS)	Scenario based (RPS targets achieved)	Market optimization based on Renewable Energy Credit clearing prices (REC and SREC), energy and capacity market results
GHG Emissions	Dispatch to price (Manually iterate on emissions price)	Single-Step optimization for annual or multi-year constraints
SO_2 and NO_x	ABB forecasts	ABB forecasts
Combined Cycle and Combustion turbine siting	Queue units with an Interconnection Service (ISA) or Facilities Study Agreement (FSA)	Units with permits added automatically. Remaining queue projects enter when economic (FSA/ISA preference)

Evolved analytical approach to evaluate compliance impacts over a wider range of state and multi-state compliance scenarios

Modeling Assumptions

	Combined Cycle	Combustion Turbine	Nuclear	Coal	Solar	Wind
Overnight Capital Costs	Brattle 2014 PJM Costs of New Entry study	Brattle 2014 PJM Costs of New Entry study	EPA v5.13	N/A	NREL ATB 2015 - 2018 Technology year	NREL ATB 2015 - 2018 Technology year
Technical Life	30	30	40	N/A	20	20
Depreciation	MACRS 20-year	MACRS 15-year	MACRS 15-year	N/A	MACRS 5-year	MACRS 5-year
Avoidable Cost	PJM 2019/2020 ACR Defaults	PJM 2019/2020 ACR Defaults	EPA Base Case v5.13	EPA Base Case v5.13	NREL ATB 2015 - 2018 Technology year	NREL ATB 2015 - 2018 Technology year
Heat Rate (Btu/KWh)	6,800[1]	10,300[1]	10,452			
Capacity Factor	Dispatchable within Model				NREL 2006 hourly shapes	NREL 2006 hourly shapes
Fuel Forecast	ABB Fall 2015 Fuel Forecast					
Locational Costs Adders	Brattle 2014 PJM Costs of New Entry study	Brattle 2014 PJM Costs of New Entry study	EIA energy market module NERC sub-regions		EIA energy market module NERC sub-regions	EIA energy market module NERC sub-regions

[1] Varies by PJM Locational Deliverability Region (GE 7FA technology)

Primary Data Sources

- Federal and State Energy Policy and Incentives:
  http://programs.dsireusa.org/system/program/
- EPA Generating Unit and Financial Assumptions:
  https://www.epa.gov/airmarkets/power-sector-modeling-platform-v513
- Natural Gas Combined Cycle and Combustion Turbine Financial Assumptions:
  https://www.pjm.com/~/media/documents/reports/20140515-brattle-2014-pjm-cone-study.ashx
- Solar and Wind Financial Assumptions:
  http://www.nrel.gov/docs/fy15osti/64077-DA.xlsm
- Solar Hourly Shapes:
  http://www.nrel.gov/electricity/transmission/solar_integration_methodology.html
- Wind Hourly Shapes:
  http://www.nrel.gov/electricity/transmission/wind_integration_dataset.html
- Variable Resource Requirement Curve and RPM Planning Parameters:
  http://pjm.com/~/media/markets-ops/rpm/rpm-auction-info/2019-2020-bra-planning-parameters.ashx