PJM's Clean Power Plan Modeling Reference Model and Sensitivities

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Reference Model

What it is

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

How should it be used?

- To convey dynamics of various stimuli on the economic viability of existing and future generation
- Only for comparison with policy cases

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 Questions Posed to PJM

What did the states ask?

Study the reliability and economic impacts of the Clean Power Plan

What is the fundamental question?

What does a significant shift from coal to natural gas, and deployment of additional renewables and/or energy efficiency mean for wholesale power costs and resource adequacy

PJM Modeling Methodology

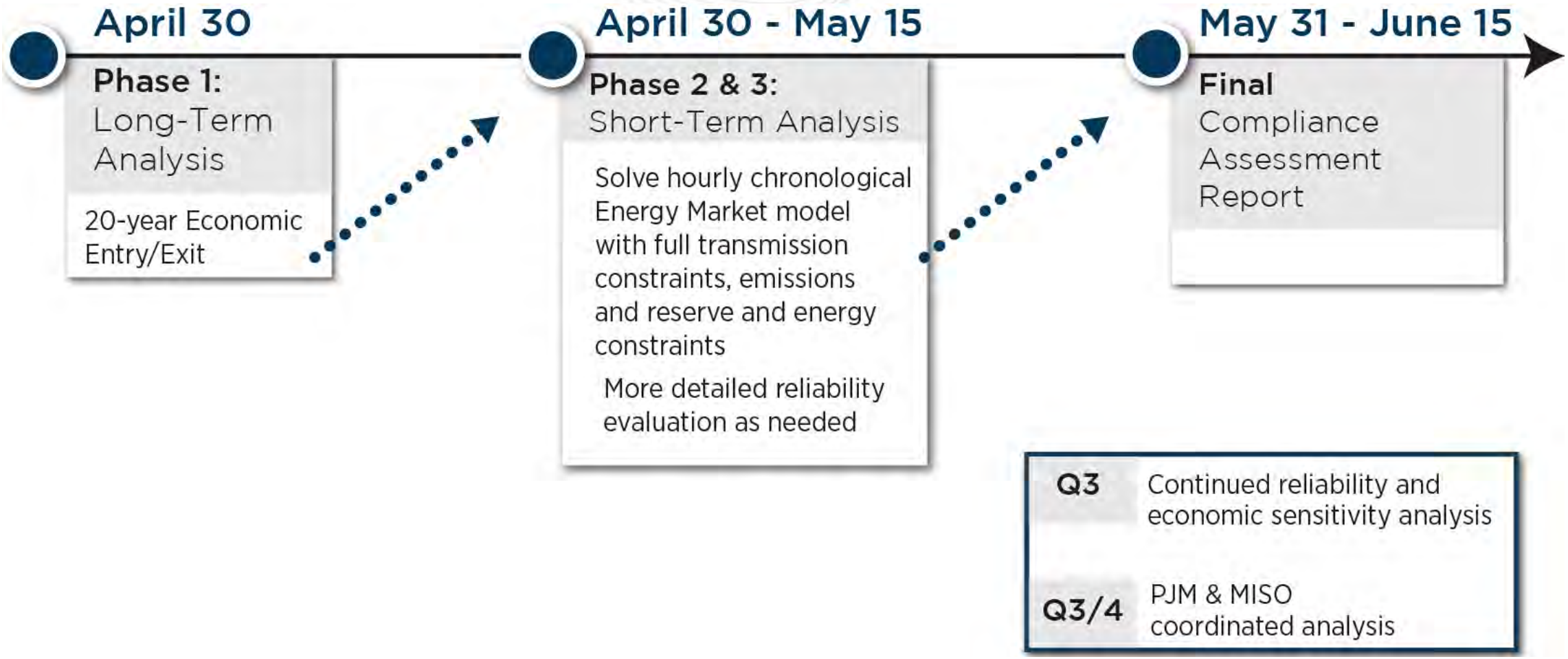
Key Assumptions

Reference Model	Assumes Production and Investment Tax Credit
Sensitivities	
Renewable Portfolio Standard (RPS)[1]	Assumes Production and Investment Tax Credit and enforces RPS through state Alternative Compliance Payments
Lower Gas	Assumes Production and Investment Tax Credit
Lower Gas + RPS	Assumes Production and Investment Tax Credit and enforces RPS through state Alternative Compliance Payments

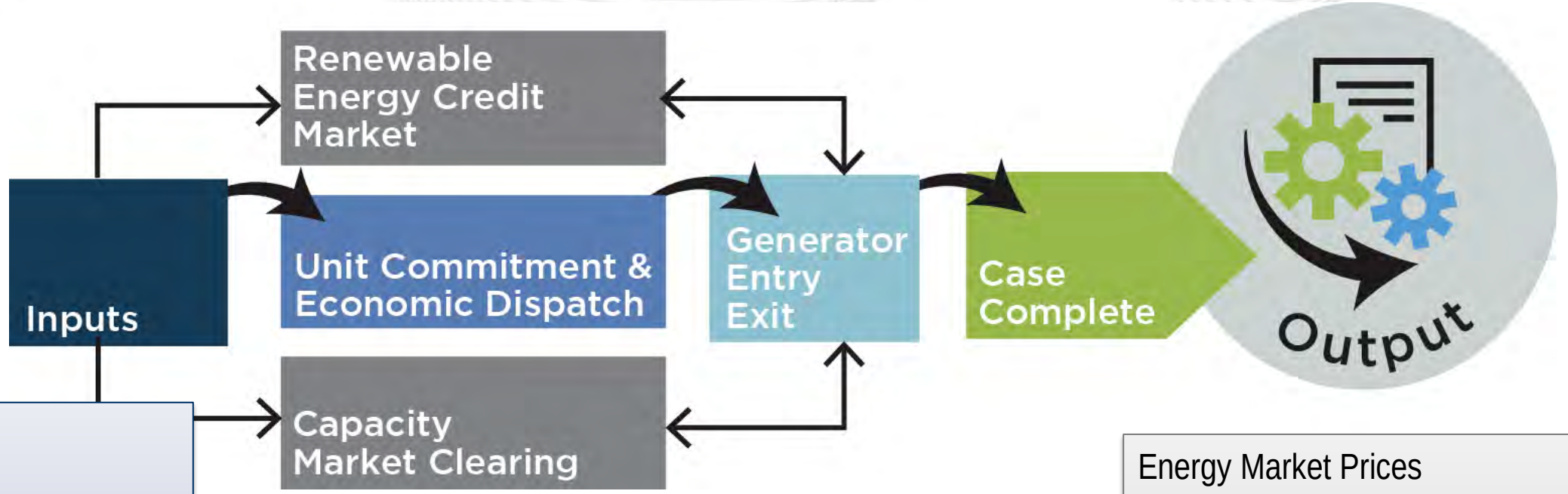
Key Inputs	Description
Reference Natural Gas Price ($2016)	$5.14/mmbtu (avg. 2016-2037)
Lower Gas Natural Gas Price ($2016)	$3.43/mmbtu (avg. 2016-2037)
Inflation	2.25%
Effective Tax Rate	40%
Weighted Average Cost of Capital	8%
Study Horizon	2018 to 2037

[1] Renewable Energy Certificates (REC) are assumed tradeable throughout the footprint. Solar RECs must be produced within the state.

Modeling Approach and Timing



What Tools are we Using to Answer the States Question?

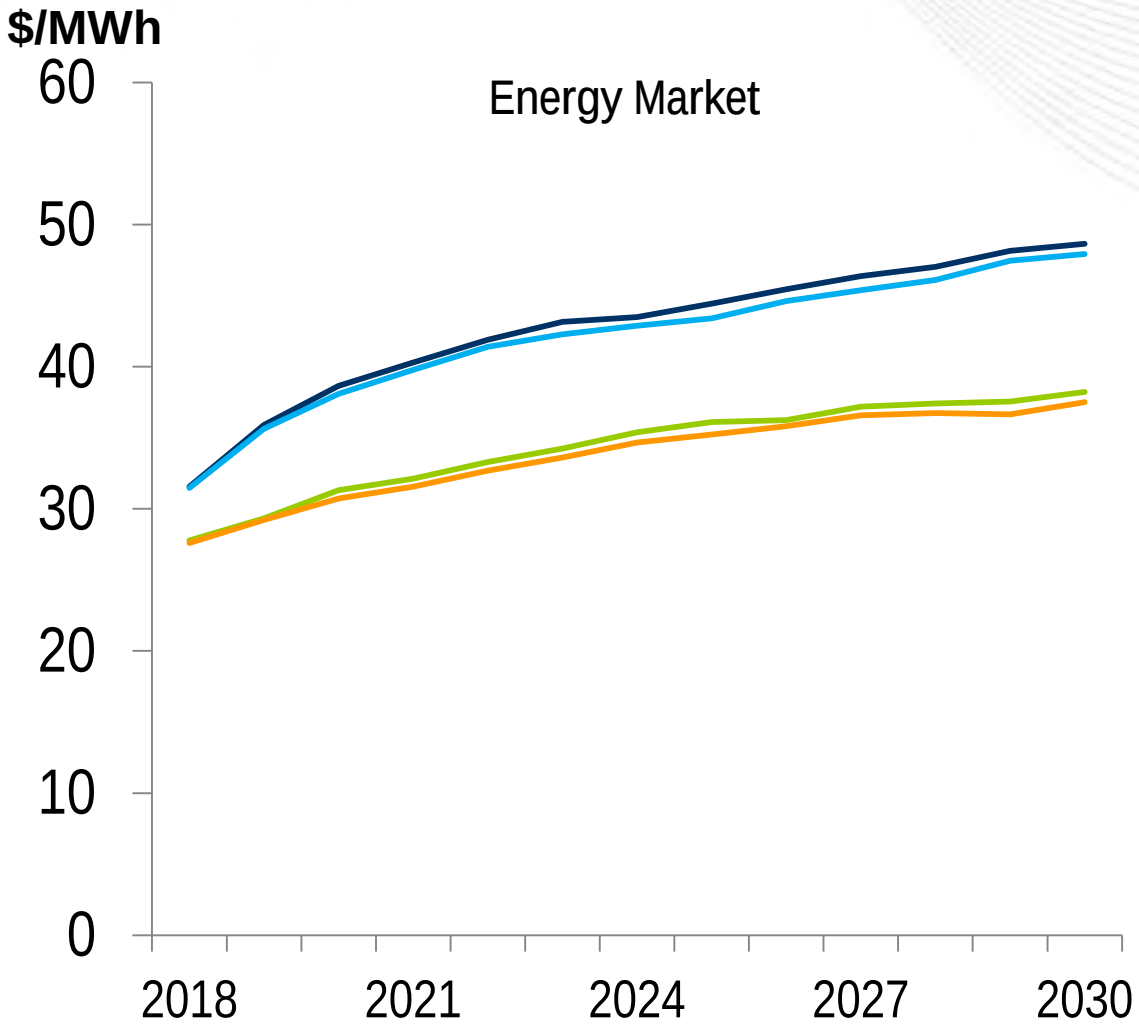


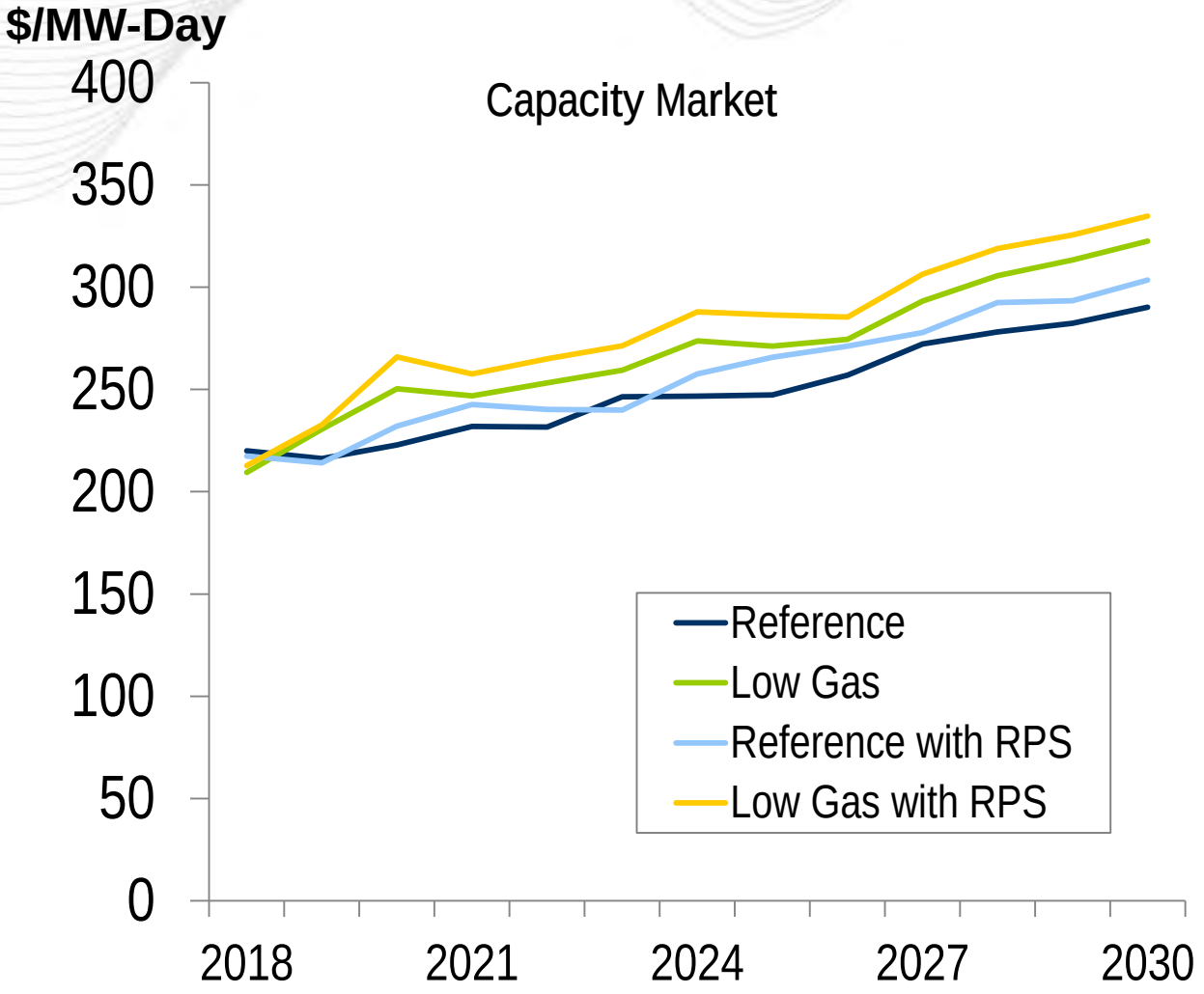
Load Forecast
Fuel Prices
Unit Operational Constraints
Emissions Constraints
Transmission Constraints
Fuel Supply Limitations
Capacity Market Bids
Renewable Portfolio Standards
Demand Response

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

Detailed Reference Model and Reference Model Sensitivity Results

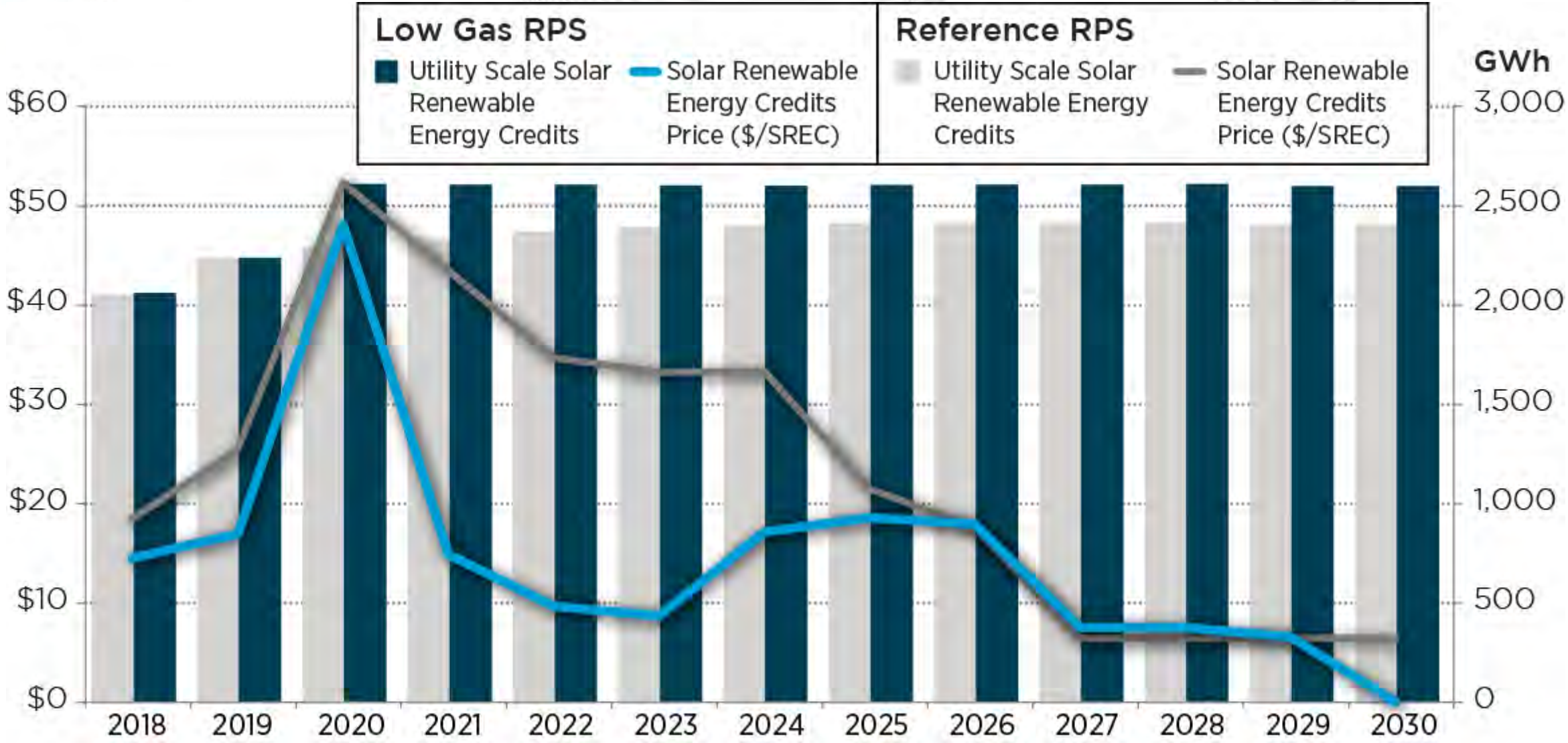
Reference Model and Reference Model Sensitivities
PJM Energy and Capacity Market Prices ($2018)





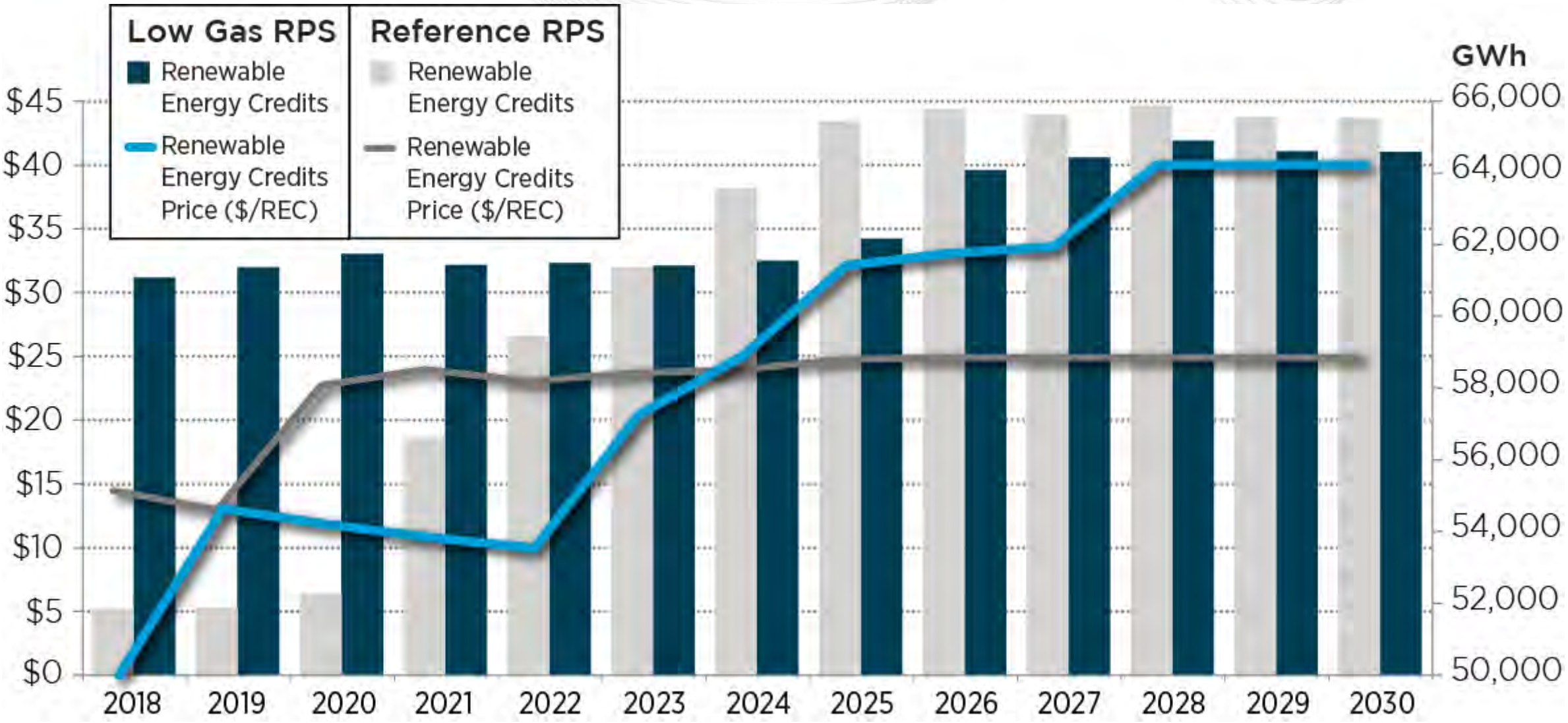
Solar Renewable Energy Credits

Weighted Average Price for PJM Region

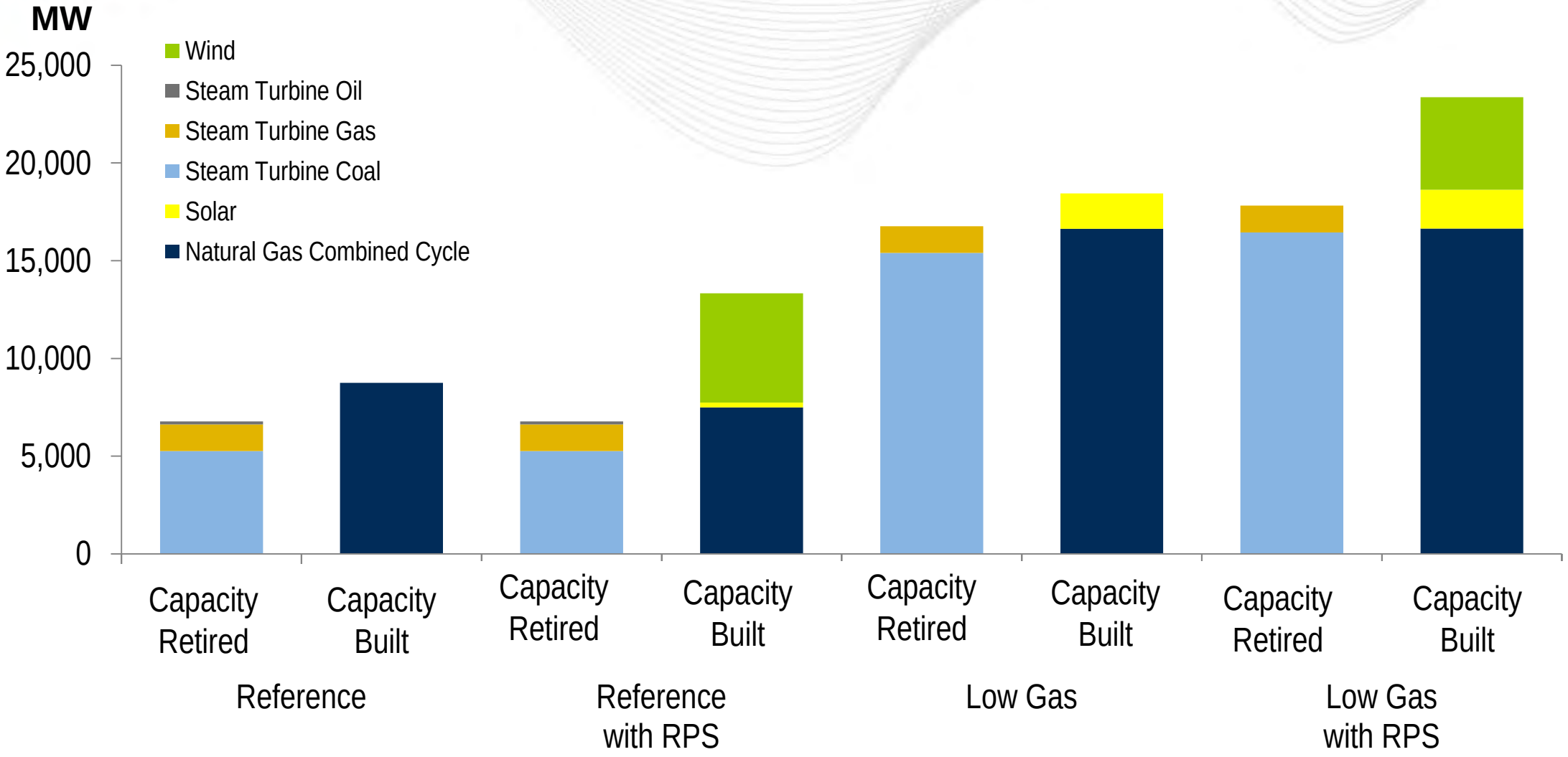


Renewable Energy Credit

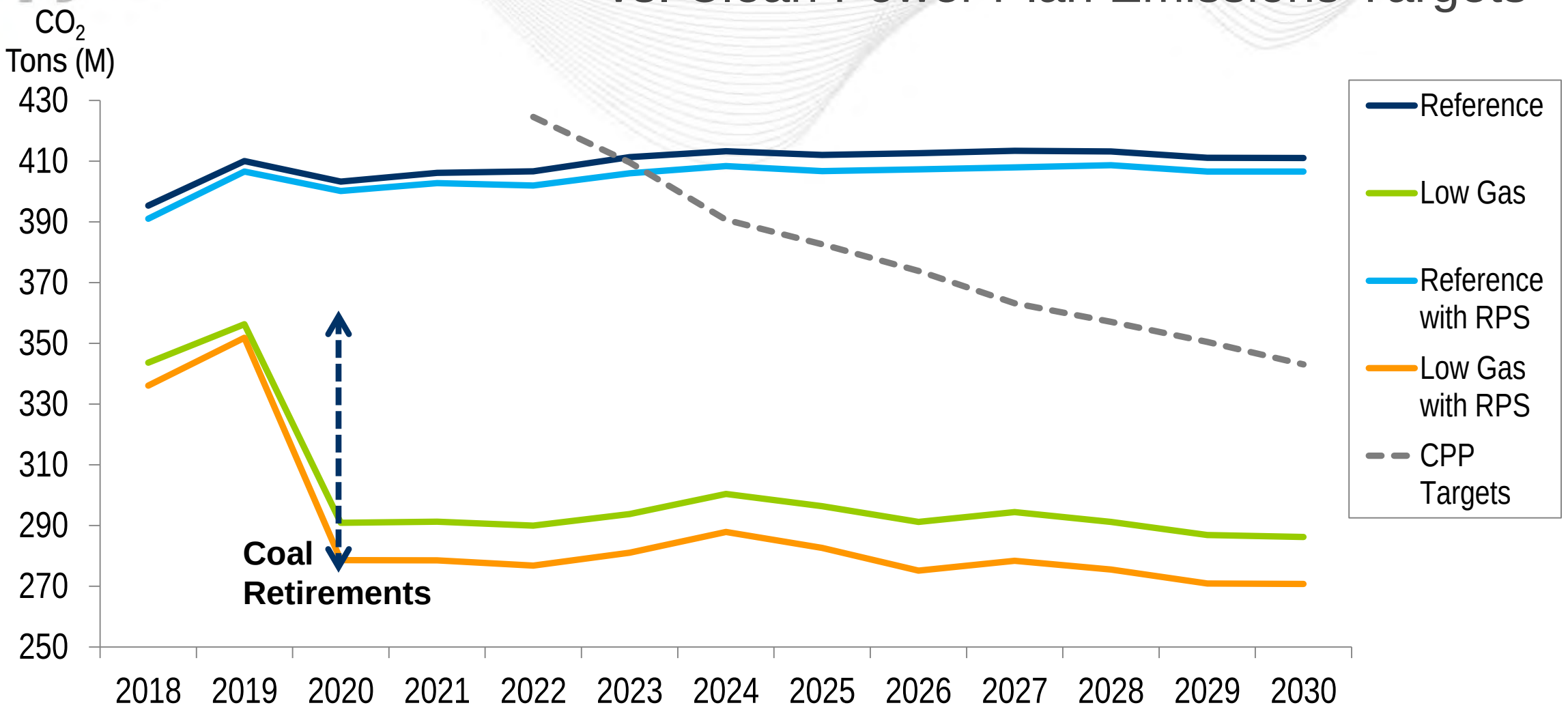
PJM Regional Price



Economic Retirements and New Entrants By 2025



PJM Region CO_2 Emissions for Existing Sources vs. Clean Power Plan Emissions Targets



Emissions and target emissions are for existing sources only covered by the Clean Power Plan regulation for existing sources.

Reference Model
Key Observations

Intermediate and Baseload Resource

- Low avoidable costs (once built) and high capacity prices enable natural gas combined cycles to enter the market despite depressed energy market prices.
- Lower gas prices will lead to greater dependence on the capacity market for cost recovery by coal and nuclear resources.
- Coal resources appear to be at greater risks than nuclear since lower natural gas prices mean not only lower margins in the energy market but also reduced run hours.

Reference Model
Key Observations

Intermittent Resources

- Wind and solar can continue to grow in a low gas price environment provided RPS is in place and alternative compliance penalties remain high.
- Solar can take advantage of resource retirements more effectively than wind due to higher capacity value (38% vs. 13%).

Emissions

Sustained lower gas prices will result in CO_2 reductions through retirements and new combined cycle entry.

Data Sources

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 clearing BRA 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