PJM CPP Reference Model and Sensitivities

Transmission Expansion Advisory Committee

April 07, 2016

Reference Model

What it is

- Simultaneous clearing of energy, capacity, REC and SREC markets that provides a 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 Assumptions

Reference Model	**Assumes Production and Investment Tax Credit[1]**
Sensitivities	
Renewable Portfolio Standard (RPS)	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.

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.

How is PJM Performing the CPP Analysis

April 31

Phase 1:
Long-Term Analysis

20-year Economic Entry/Exit

April 31 - May 15

Phase 2 & 3:
Short-Term Analysis

Solve hourly chronological Energy Market model with full transmission constraints, emissions and reserve and energy constraints

More detailed reliability evaluation as needed

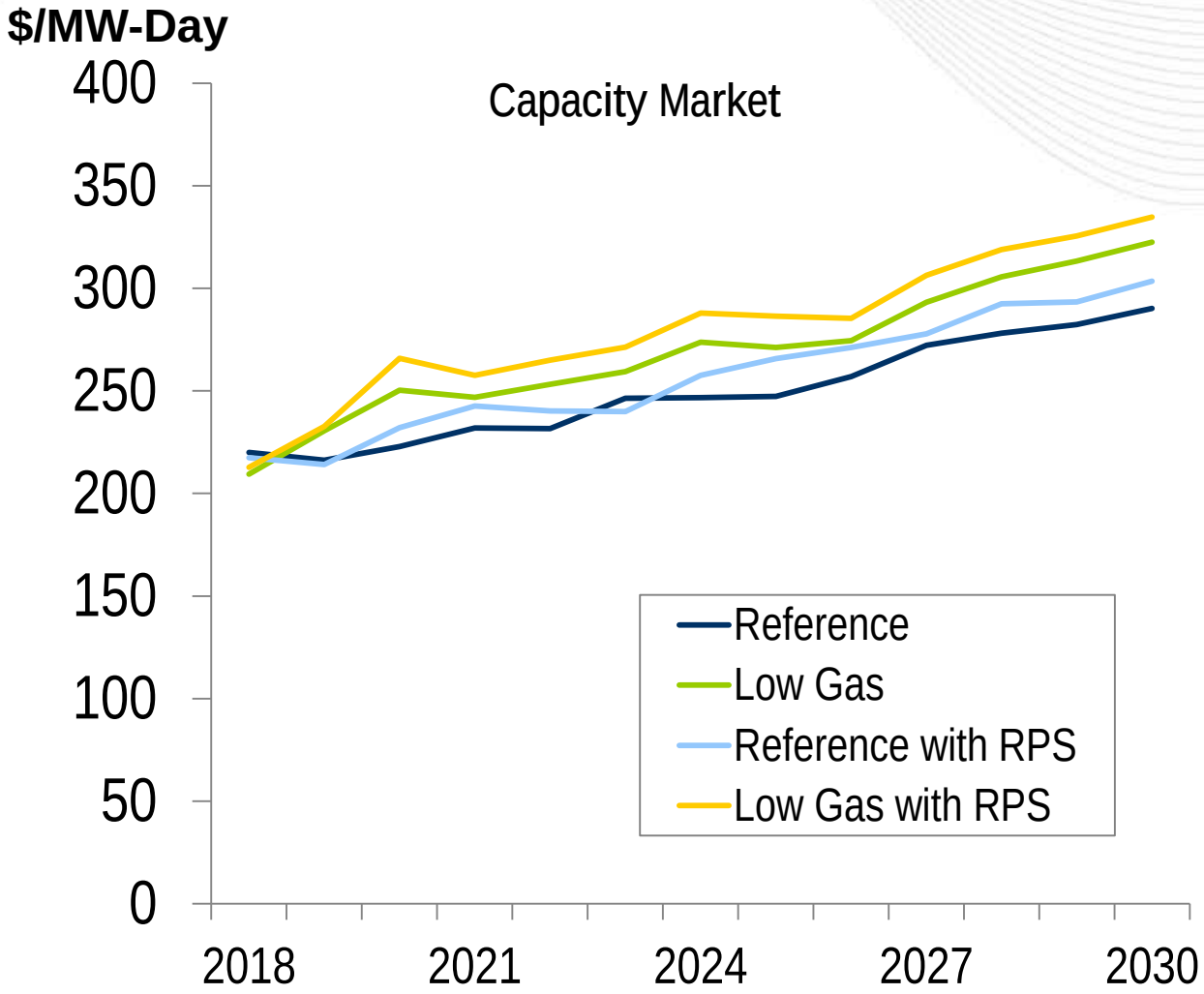
May 31 - June 15

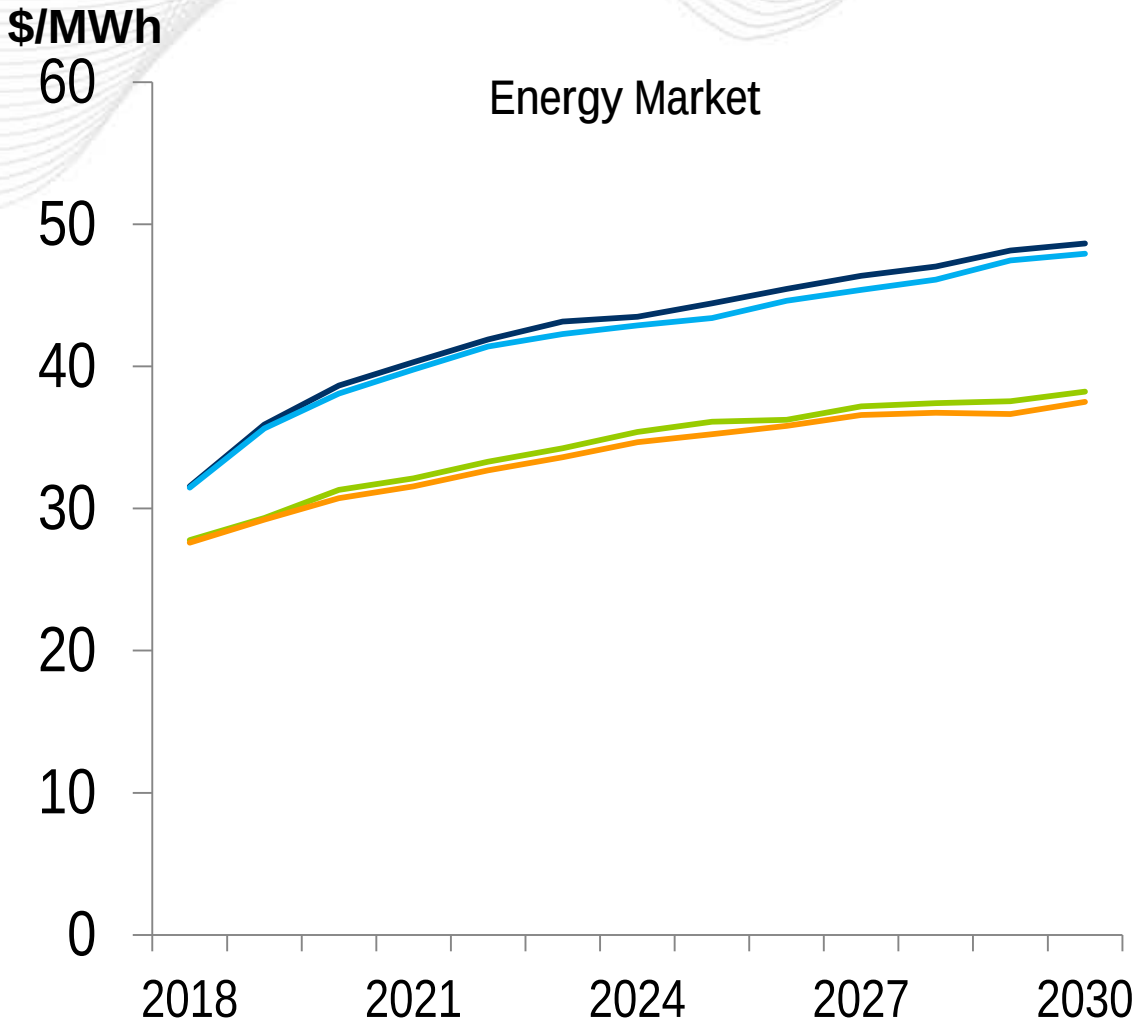
Final
Compliance Assessment Report

Q3	Continued reliability and economic sensitivity analysis
Q3/4	PJM & MISO coordinated analysis

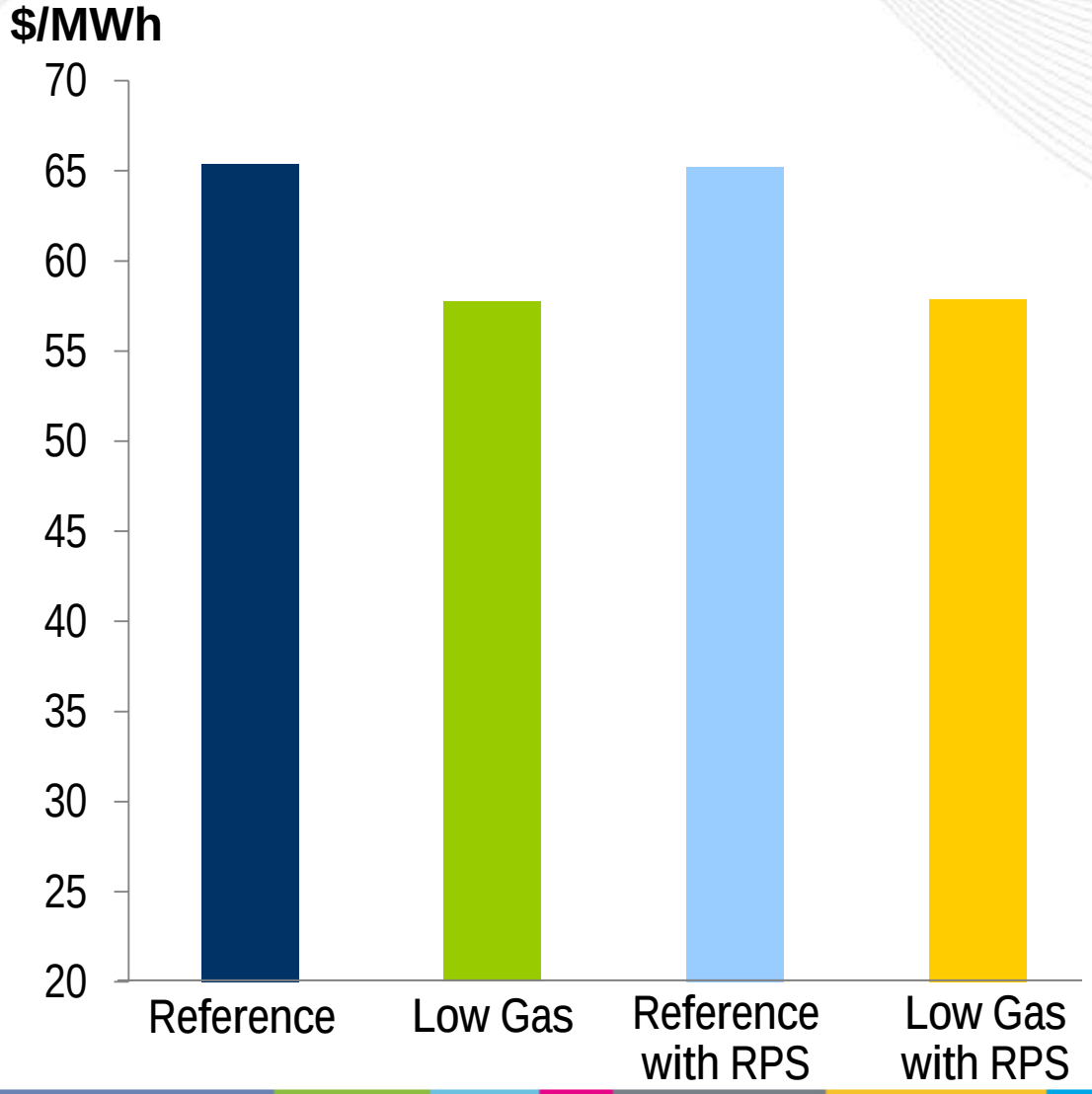
Detailed Reference Model and Reference Model Sensitivity Results

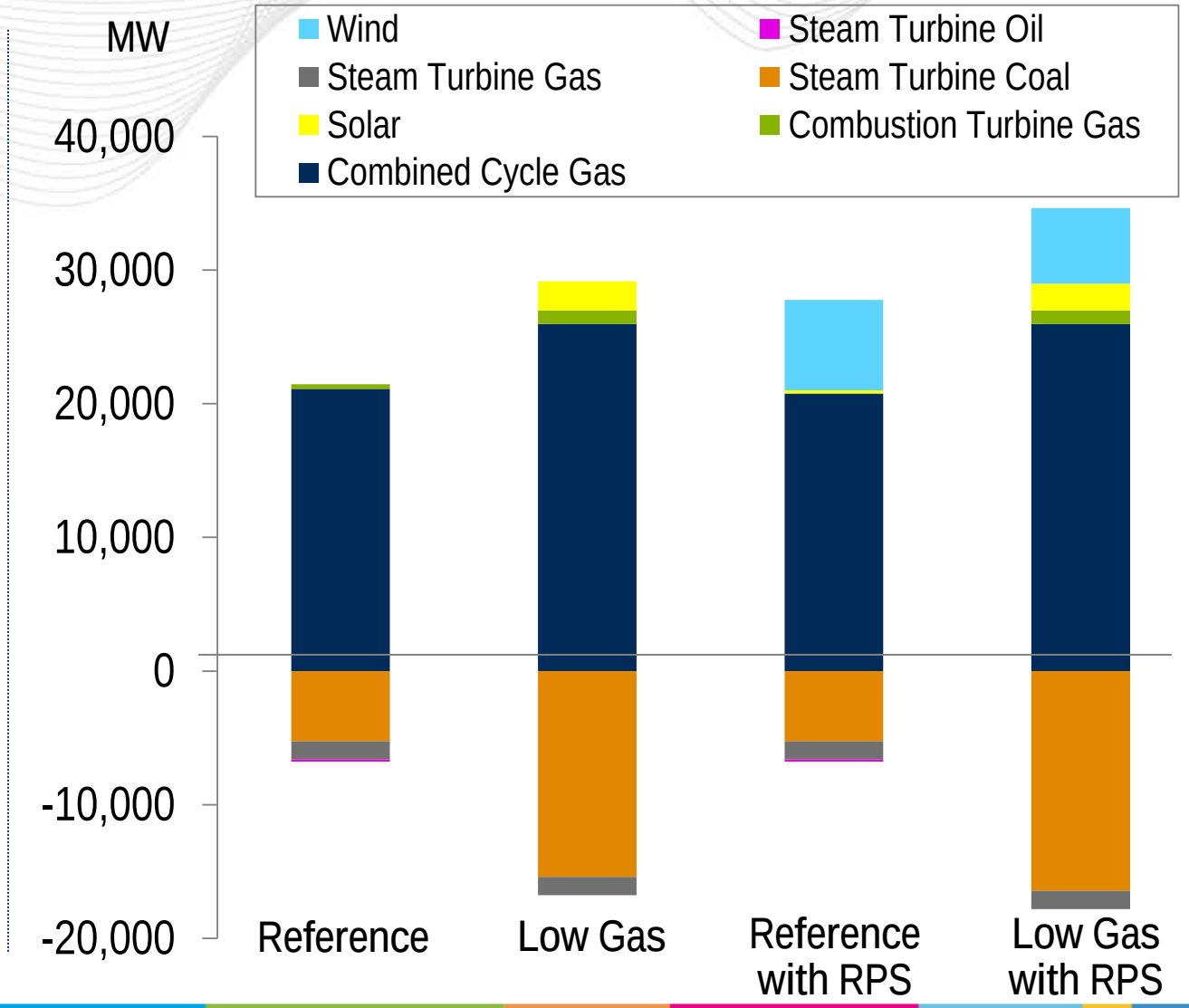
Reference Model and Reference Model Sensitivities
PJM Capacity and Energy Market Prices ($2018)





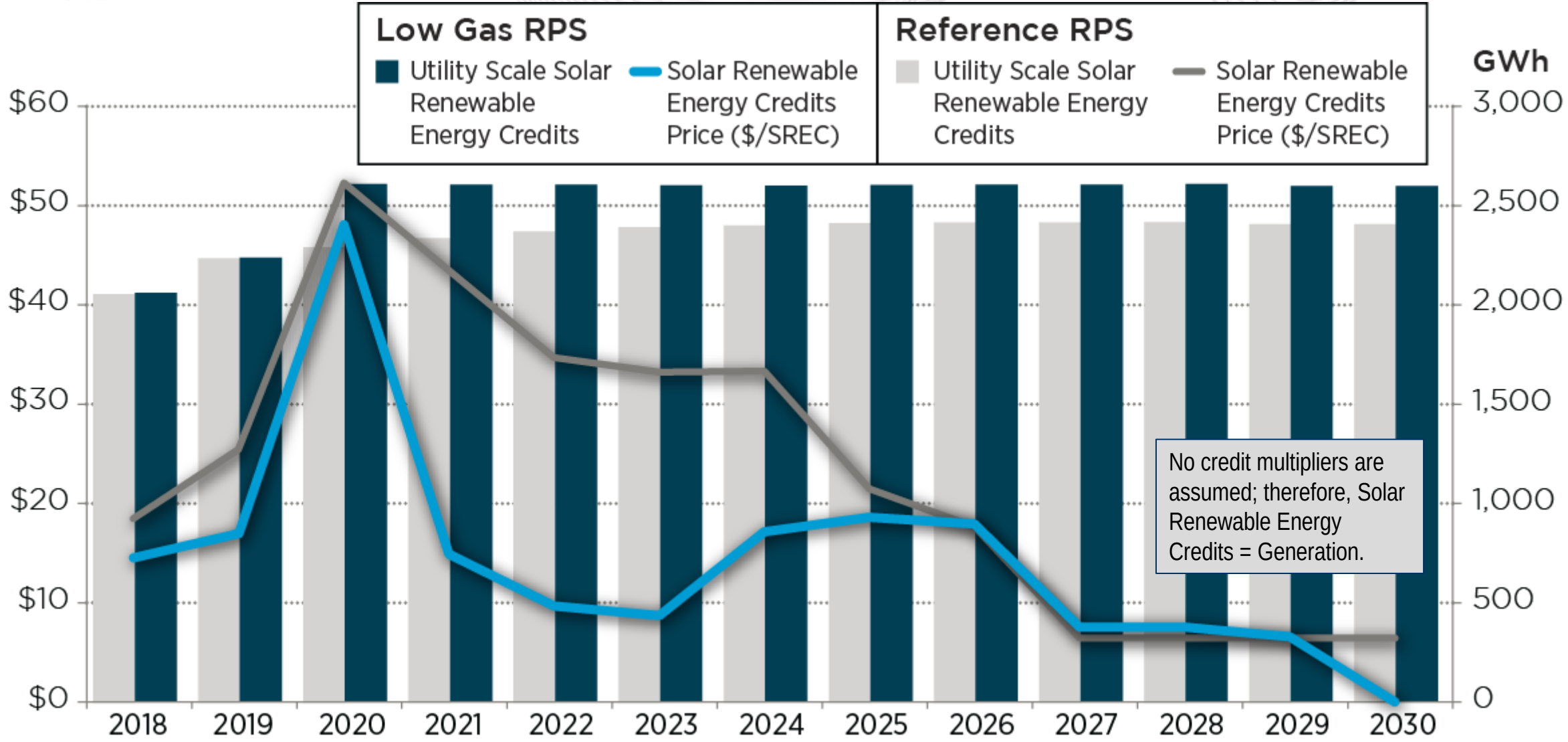
Levelized Energy & Capacity Market Prices ($2018) vs. Change in Generating Capacity





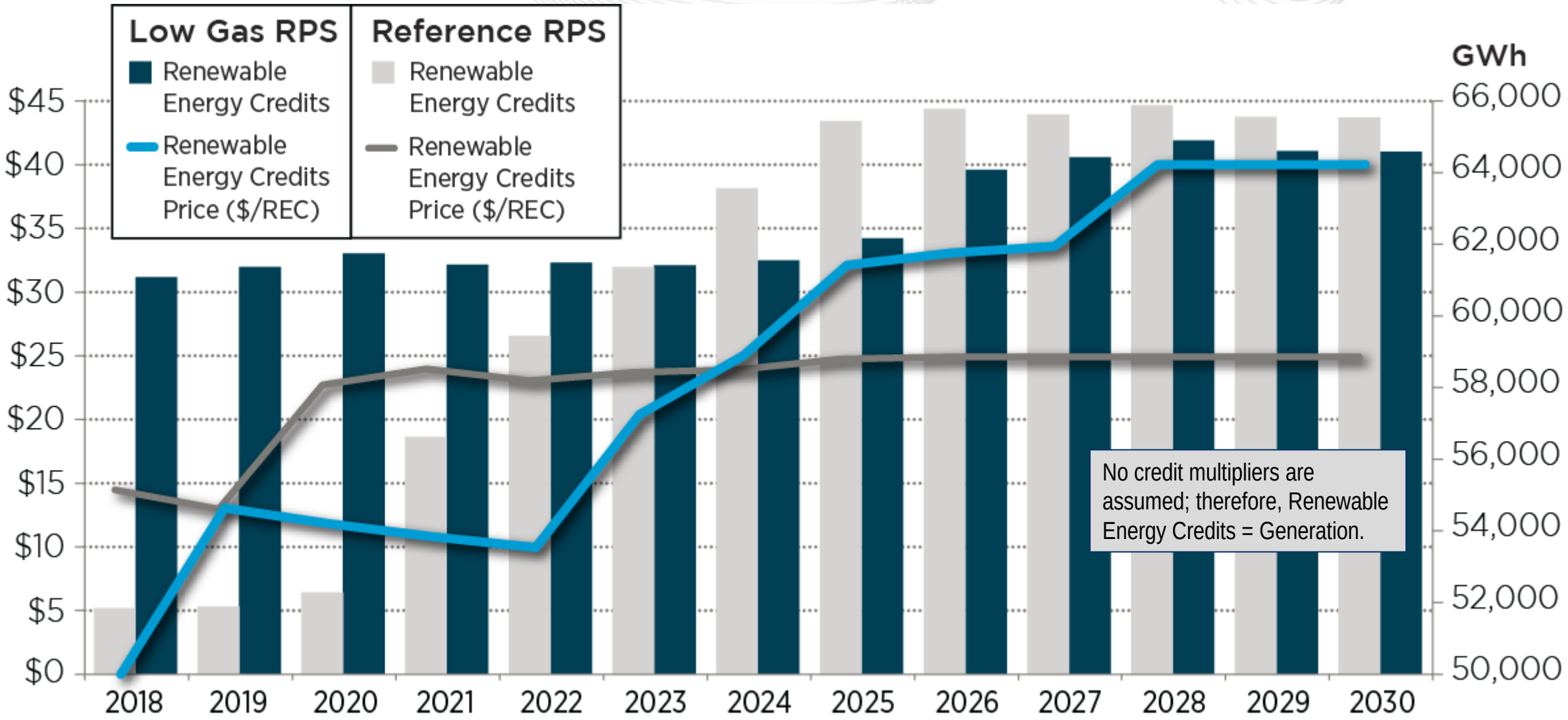
Solar Renewable Energy Credits

Weighted Average Price for PJM Region

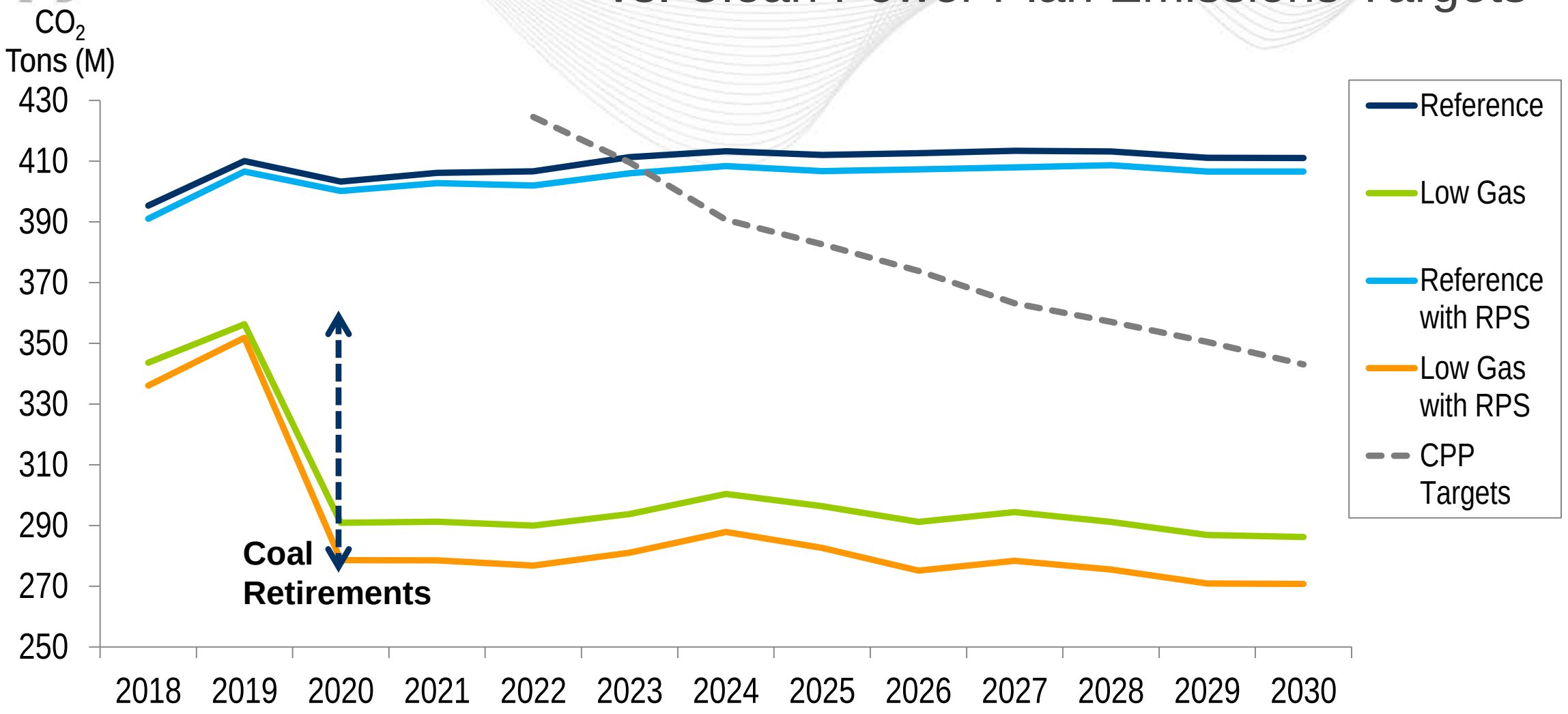


Renewable Energy Credit

PJM Regional Price



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.

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)

Common Questions

Common Questions

- Why is PJM performing analysis of the Clean Power Plan?
  - The Organization of PJM States Inc. (OPSI) requested PJM to perform analysis, and PJM worked with the states and stakeholders to define the scope and timeline for the analysis. http://pjm.com/~/media/committees-groups/committees/teac/20160211/20160211-pjms-modeling-approach-to-the-final-cpp-emissions-guidelines.ashx
- How does PJM treat expected unit technical life?
  - PJM's modeling reflects only market based entry/exit with the exception of announced retirements.
- Does PJM model any minimum or maximum limits for resources?
  - No, resources enter based on energy market revenues, capacity market revenues, solar and non-solar Renewable Energy Credits, and applicable Federal Tax Incentives.
- How are Fixed Resource Requirement (FRR) resources treated in the capacity market simulation?
  - All resources within the PJM footprint participate in the capacity market based on their unforced capacity. FRR resources are assumed to be price-takers, but can retire as a function of cost-recovery.

Common Questions

- Is PJM doing resource planning?
  - Absolutely not. The resource locations are all based on queue sites that are advanced in the interconnection queue study process. Wind and solar locations were added based on NREL sites nearest to the PJM transmission system.
  - The model is simply selecting resources based on when they become available given the various market prices.
- What is the impact of not representing transmission in the 20-year model?
  - In the short-run (< 5 years) some resources benefit significantly from the presence of transmission congestion, just as transmission congestion represents a limitation for other resources.
  - In the long-run, through PJM's baseline and market efficiency processes transmission congestion should be mitigated, such that resources across the interconnected system compete based on fundamental operating characteristics.
- How does PJM represent the external world? PJM uses the same external world representation used in PJM's Day-Ahead Market intended to replicate flow impacts on significant transmission constraints. However, in the model, external resources are not bid into the market.

Common Questions

- How are retirement and entry decisions made within the model?
  - Plexos performs a single step optimization of new entry and retirements for a 20-year horizon.
  - Within the 20-years the resource must have a positive net present value given capacity and energy market revenues, and for renewables, revenues from the renewable energy credit trading market.
  - Market revenues must exceed levelized capital payments, annual avoidable costs and production costs including cost of capital.
- Does PJM model any confidential data?
  - PJM's model is based on publically available data with the exception of vendor supplied fuel and emissions forecasts. The model was tuned in coordination with various market operations and system planning departments, consequently not all data or assumptions will be provided publicly.

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