PJM Reliability Pricing Model:

Analysis in Support of
The Appropriate Reference Unit

Presented to PJM

On behalf of the P3 Group

11 February 2022

Contents

Objective: Provide an overview of the research and report regarding the appropriate reference unit and considerations for adjustments to the VRR Curve for the Reliability Pricing Model ("RPM") Quadrennial Review

Report Overview:

- **Generation Mix:** State policies and new technologies should inform PJM's reference unit now and going forward
- **Cost and Uncertainty:** The estimated costs and Net CONE for a combined cycle is more uncertain than for a combustion turbine
- **VRR Curve:** Should not be steepened given uncertainty and lack of foundation
- **Conclusion:** The combustion turbine, for now, reflects a pure capacity unit and sends the right signal

In setting the reference unit, consistency and common sense should prevail

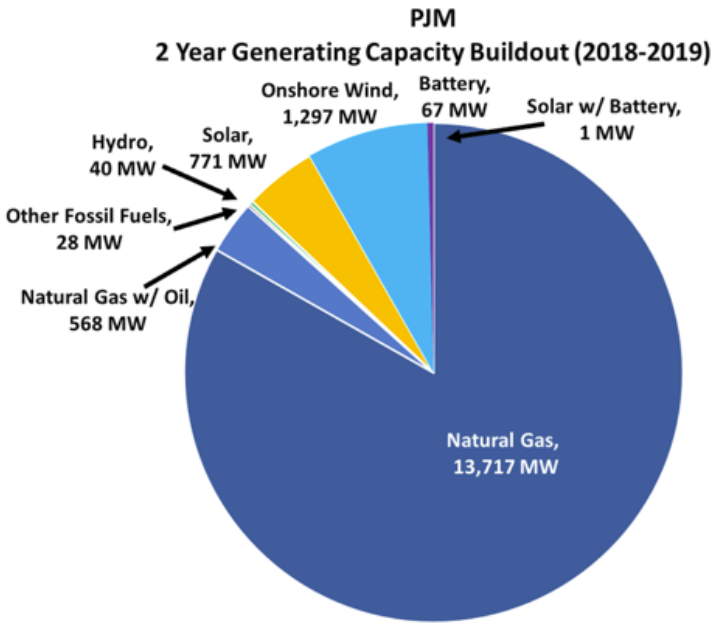
Analysis in Support of the Appropriate Reference Unit

GENERATION MIX

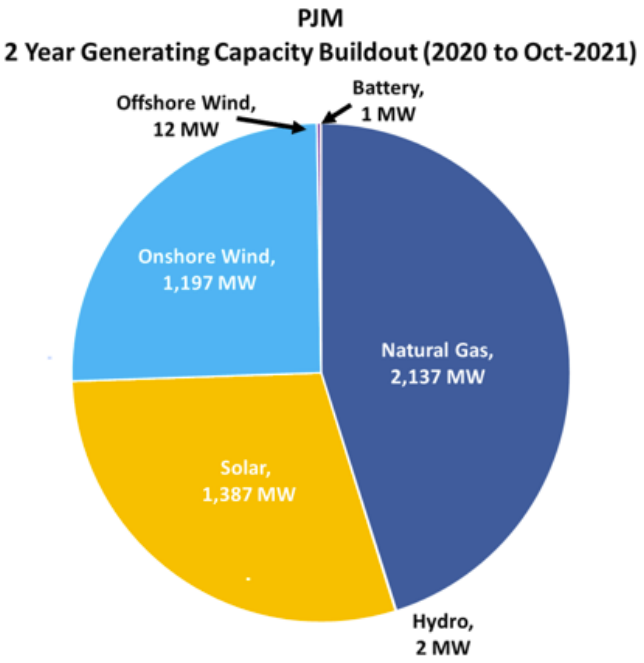
Generation Mix

Recent buildout in PJM indicates a shift toward clean energy

3 Year Existing Generating Capacity Buildout (2018 to Current)



1 Year Existing Generating Capacity Buildout (2020 to Current)



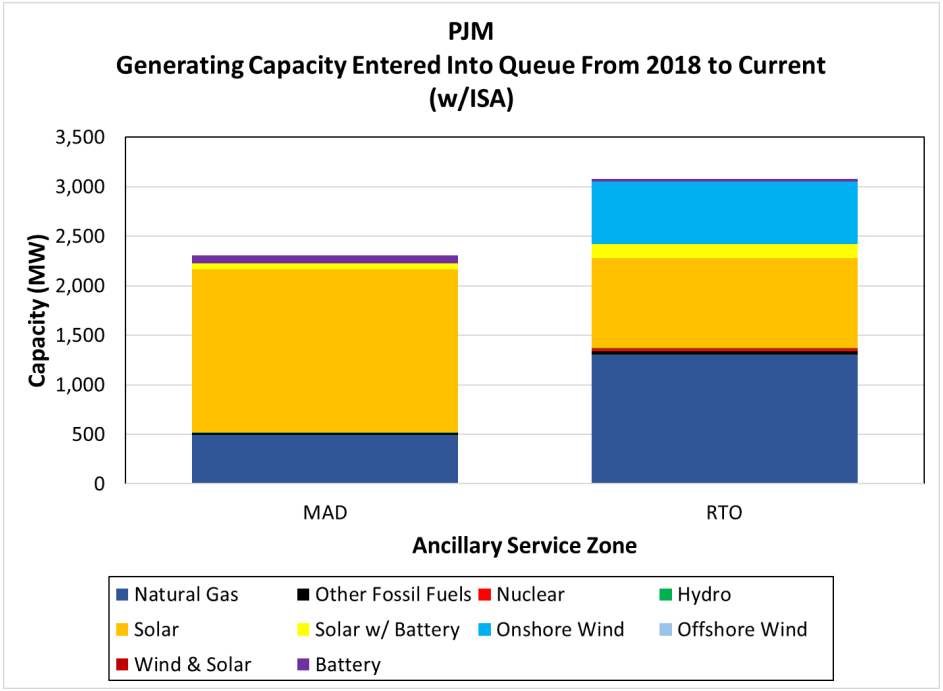
Source: Energyzt analysis of PJM Queue data.

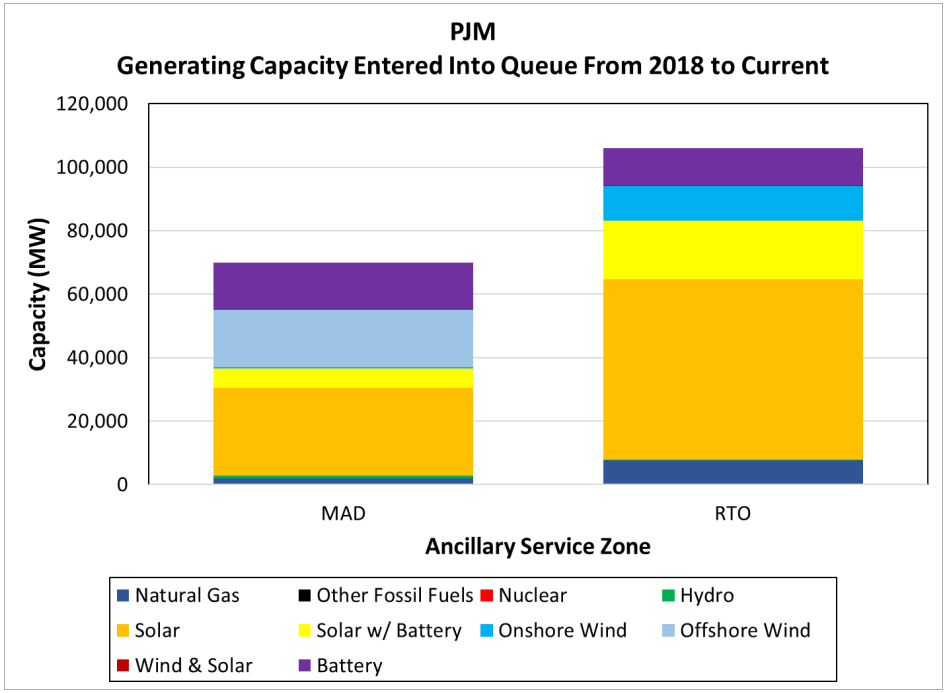
The past two years have seen a shift in build-out away from natural gas

Generation Mix

PJM has a queue that is filled with solar and wind

Generating Capacity in Queue with and without an ISA (2018 to Current Entry Year)



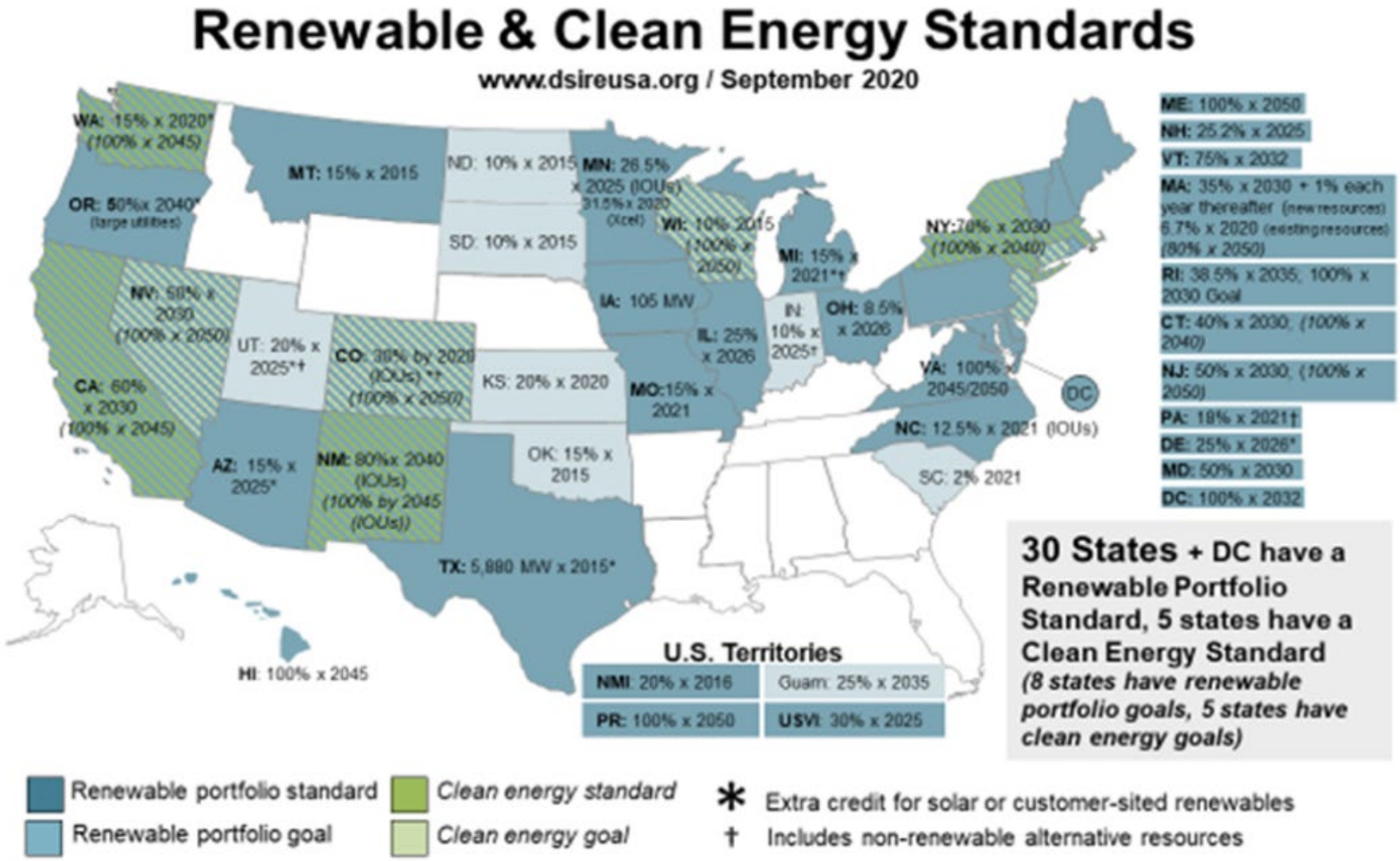


PJM has been approving renewable projects at a rate comparable to natural gas

ENERGYZT

Generation Mix

Nearly all PJM states have some level of clean energy goals



Illinois, New Jersey and Virginia have announced 100% renewable goals

ENERGYZT

Generation Mix

Although the state requirements vary, some have near-term targets

PJM States
Summary of Renewable and Carbon Emission Reduction Goals

State	RPS Targets	Economy-wide Carbon Emissions Targets[7]
Delaware	40% by 2026	30% below 2008 levels by 2030
Illinois	45% by 2026, 100% by 2050	26-28% below 2005 levels by 2025
Indiana	10% by 2025	-
Kentucky	-	-
Maryland	50% by 2030, 100% by 2040	50% below 2006 levels by 2030, carbon neutral by 2050
Michigan	15% by 2021	28% reduction by 2025, carbon neutral by 2050
North Carolina	12.5% by 2021	70% below 2005 levels by 2030, carbon neutral by 2050 (power sector specific)
New Jersey	50% by 2030, 100% by 2050	80% below 2006 levels by 2050
Ohio	8.5% by 2026	-
Pennsylvania	18% by 2021	26% below 2005 levels by 2025, 80% by 2050
Tennessee	-	-
Virginia	100% by 2045 (Dominion) 100% by 2050 (AEP)	Net zero by 2045
Washington, DC	100% by 2032	50% below 2006 levels by 2032, 80% by 2050
West Virginia	-	-

Long-term targets also will impact resource choice, siting and retirements

Generation Mix

Mandates are not needed to prevent fossil generation build-out

Illinois: On September 15, 2021, Illinois Governor J. B. Pritzker signed the Climate and Equitable Jobs Act into law which, among other things, requires all private coal-fired and oil-fired electric generating units to reach zero emissions by January 1, 2030. All privately-owned natural gas-fired units must reach zero emissions by 2045, subject to several interim targets that are designed to force closures prior to those dates.

New Jersey: On November 15, 2021, the New Jersey Senate passed Senate Resolution 17 which urges the Governor to impose an immediate moratorium on fossil fuel project until, ". . . the State adopts rules regulating CO2 and other climate pollutants adequate to achieve the 80 percent reduction in greenhouse gas emissions from 2006 levels by 2050 as required under the Global Warming Response Act."

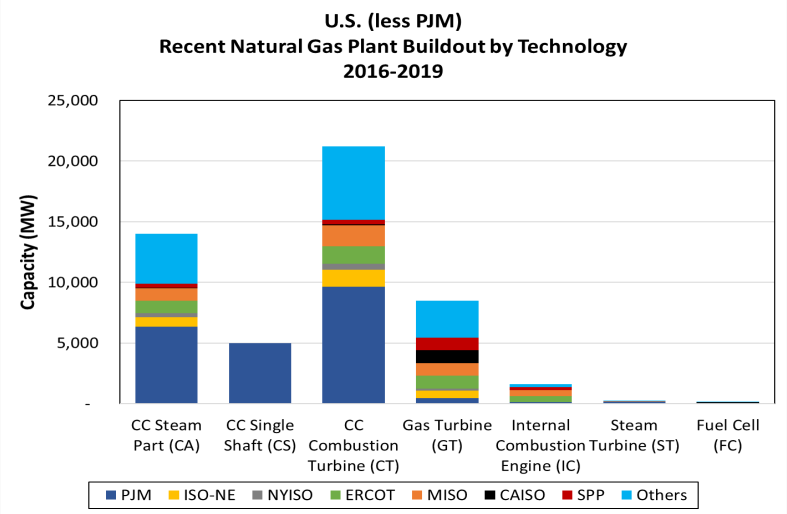
Virginia: On April 11, 2020, Virginia Governor Ralph Northam signed the Virginia Clean Economy Act into law which, among other things, creates a "schedule by which Dominion Energy Virginia and American Electric Power are required to retire electric generating units located in the Commonwealth that emit carbon as a by-product of combusting fuel to generate electricity." Specifically, by December 31, 2045, all electric generating units located in Virginia that "emit carbon as a by-product of combusting fuel to generate electricity" would be required to retire . . .

PJM should assume the states will meet their goals and plan accordingly

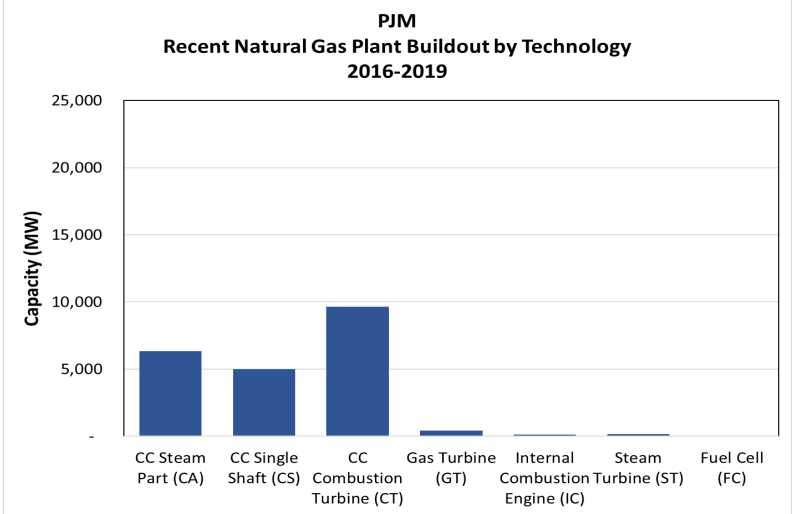
Generation Mix

PJM's has a much more limited set of new entry technologies

U.S. RTO/ISO Build-out



PJM Build-out



Natural Gas Recent Buildout 2016-2019

Location	CC Steam Part (CA)	CC Single Shaft (CS)	CC Combustion Turbine (CT)	Gas Turbine (GT)	Internal Combustion Engine (IC)	Steam Turbine (ST)	Fuel Cell (FC)	Total
PJM	6,347	4,988	9,630	439	127	161	10	21,701
ISO-NE	801	-	1,418	644	5	-	23	2,890
NYISO	300	-	470	140	-	-	8	917
ERCOT	1,020	-	1,442	1,069	502	-	-	4,032
MISO	1,056	-	1,742	1,028	478	33	-	4,336
CAISO	16	-	71	1,109	7	-	85	1,288
SPP	350	-	369	993	265	-	-	1,976
Others	4,123	-	6,053	3,072	212	1	3	13,464
Total	**14,012**	**4,988**	**21,195**	**8,492**	**1,594**	**195**	**128**	**50,604**
% of Total (PJM)	**29%**	**23%**	**44%**	**2%**	**1%**	**1%**	**0%**	**100%**
% of Total (Less PJM)	**27%**	**0%**	**40%**	**28%**	**5%**	**0%**	**0%**	**100%**
PJM % of Total for Technology	**45%**	**100%**	**45%**	**5%**	**8%**	**83%**	**8%**	**43%**

Other markets have reciprocating engines and aeros to integrate renewables

PJM's RPM parameters create barriers to entry for new technologies

July 21, 2021

- CONE construct does not reflect market realities
- System does not distinguish or monetize valuable capacity characteristics
- Financing is difficult to obtain for anything other than CCs and CTs
- New technologies are locked out

July 26, 2021

- Aeros are being built in areas with highly integrated renewables
- PJM market is challenging to enter
- Complex energy and capacity market variability make it difficult to obtain financing
- Market niche has been utilities, COOPs, munis

PJM's market structure and market conditions challenge new entry

Generation Mix

The reference unit should reflect each state's policy requirements

- A Reference Unit should be a technology that can be developed in a region
- In areas with environmental goals, reference units should reflect those goals:
  - For example, Illinois, New Jersey and Virginia 100% Renewable Portfolio Standards make it difficult to site new fossil fuel units in those state
  - States with less restrictive near-term targets that have not yet been met also would argue for a renewable hybrid as the Reference Unit
- Renewable resource reference units also should include storage capability to meet consistent reliability standards with alternatives
- A potential exception could be reliability units that support increasing integration of renewable resources (e.g., ramping, fast-start capability)
  - Such interim resources would need to reflect reliability needs with implementation of environmental goals
  - Any fossil fuel reliability units would need to be retired in a timeframe consistent with policy goals (e.g., by 2045 for Virginia)
- Fossil fuel units in the region should be compensated using parameters based on the net CONE of the unit that would be built if an existing unit retired

A renewable/battery hybrid is required to equate capacity capability

Analysis in Support of the Appropriate Reference Unit

COST AND ESTIMATION UNCERTAINTY

Cost and Estimation Uncertainty

The reference unit should reflect the changing generation mix

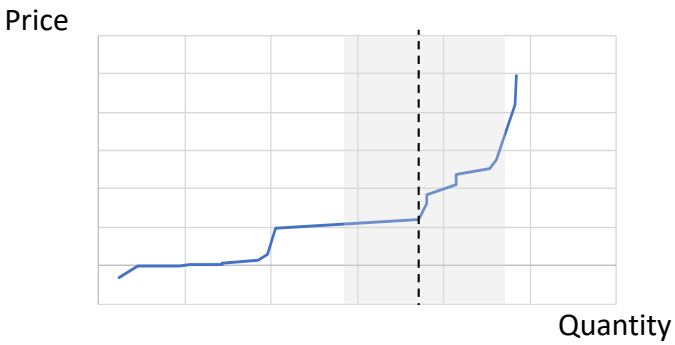
- There is no doubt that PJM and the rest of the Eastern Interconnect will experience a significant change in generation mix over the next 10 years
  - New England, New York and states within PJM are procuring renewable resources
  - PJM states have significant renewable resource goals to be achieved by 2045
- As renewables come online, the energy supply curve shifts
  - Lower energy prices
  - Changes in price volatility tied to supply curve impacts and intermittent generation
- Natural gas-fired generation will have lower capacity factors as they are displaced by renewables
  - Lower dispatch
  - Lower demand for natural gas
- Natural gas prices will become more volatile
  - Impacts Henry Hub prices
  - Impacts basis differentials

This creates significantly more uncertainty – why change the reference unit now?

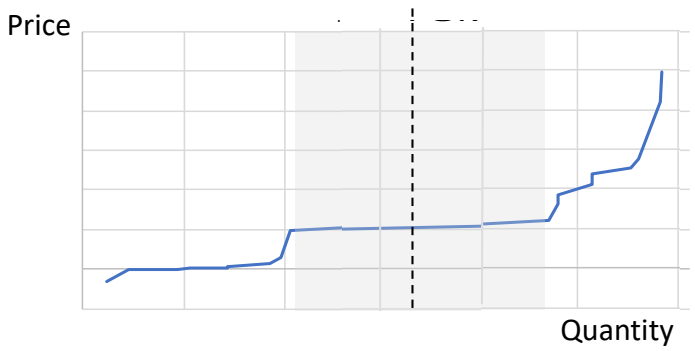
Cost and Estimation Uncertainty

As renewables come online, the supply curve shifts

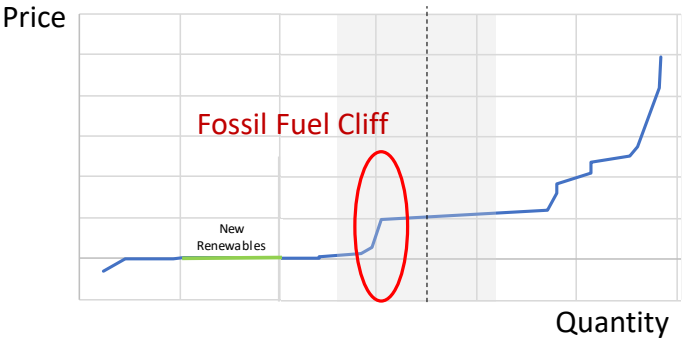
Positive Energy Market Value
Due to Scarcity



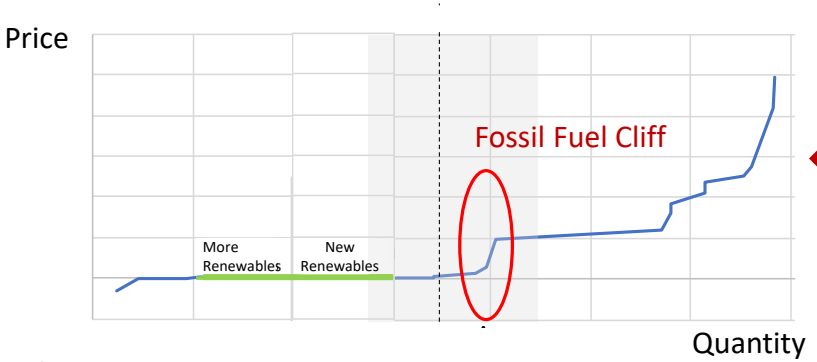
Minimal Energy Market Value
Due to Excess Supply and "Flat Part of the Curve"



Reduced Dispatch of Fossil Fuel Units
and Retirements Due to Renewables



Even the Most Efficient Fossil Fuel Units
Rarely Operate



Source: Energyzt

Renewable integration creates a significant amount of market uncertainty

Cost and Estimation Uncertainty

The combined cycle Net CONE has greater uncertainty

Reasons Why the Combined Cycle Creates More Risk

Gross CONE	E&AS	Operations
• Wider variation across estimates • Impacted by assumed location • Higher capital costs more likely to be impacted by inflation and supply chain challenges • Brattle chose the low end of the range	• Higher portion of revenues come from E&AS • Market conditions have a greater impact on E&AS and associated Net CONE • Highly uncertain market evolution translates into higher uncertainty in E&AS estimation and therefore Net CONE	• Greater variability in operating costs • Less able to support renewable integration compared to other technologies • Dispatch dependent on spark spread, which can swing capacity factors across a wide range

PJM's own calculation of Net CONE across the region can measure uncertainty

Cost and Estimation Uncertainty

Both NYISO and ISO-NE use combustion turbines as reference units

NYISO Net CONE Capital Cost Estimates ($2020/kW)

	C - Central	F - Capital	G - Dutchess	G - Rockland	J - NYC	K - Long Island
Simple Cycle Peaking Plant Technologies						
3x0 Siemens SGT-A65	$1,928	$1,945	$2,099	$2,161	$2,680	$2,211
1x0 GE 7F.05 (with Dual Fuel and SCR)	$1,315	$1,324	$1,342	$1,403	$1,817	$1,488
1x0 GE 7F.05 (Gas Only, without SCR)	$1,072	$1,082	-	-	-	-
1x0 GE 7HA.02 (with Dual Fuel and SCR)	$1,050	$1,054	$1,065	$1,100	$1,353	$1,170
1x0 GE 7HA.02 (Gas Only, without SCR)	$831	$837	-	-	-	-
Informational Combined Cycle Plants						
1x1 GE 7HA.02 (with SCR)	$1,401	$1,421	$1,547	$1,649	$1,961	$1,832
Energy Storage						
BESS 4-hour	$1,539	$1,552	$1,565	$1,620	$1,910	$1,649
BESS 6-hour	$2,146	$2,166	$2,184	$2,263	$2,592	$2,326
BESS 8-hour	$2,753	$2,778	$2,802	$2,906	$3,273	$3,004

Note:
[1] Estimates for the Siemens SGT-A65 and informational 1x1 GE 7HA.02 combined cycle units are specified with dual fuel in Load Zone G (Dutchess County), Load Zone G (Rockland County), NYC, and LI, and are specified as a gas-only design in Load Zone C and Load Zone F.
[2] All estimates include construction financing costs.

Source: Analysis Group and Burns & McDonnell, "Independent Consultant Study to Establish New York ICAP Demand Curve Parameters for the 2021/2022 through 2024/2025 Capability Years – Interim Final Draft Report," August 5, 2020, Table 24, p. 47, 214567fb-b960-233f-bcda-4b919678bce4 (nyiso.com)

Brattle's estimates are well below the estimated costs from NYISO

Cost and Estimation Uncertainty

PJM's estimates illustrate the CC's sensitivity to market conditions

Default Zonal Net CONE

All quantities are in $/MW-Day (Nameplate) and Default Net CONE is in $/ICAP-MW-Day

Combustion Turbine			
		Gross CONE	$294
		Net Reactive Service Revenue Offset	$6.02
		Capacity Value (% Nameplate MW)	NA
Zone	Net E&AS* Revenue Offset	Net CONE	Default Net CONE ($/ICAP MW-Day)
AECO	$36.72	$251	$251
AEP	$66.47	$222	$222
APS	$86.40	$202	$202
ATSI	$72.95	$215	$215
BGE	$78.23	$210	$210
COMED	$48.17	$240	$240
DAYTON	$71.04	$217	$217
DEOK	$77.93	$210	$210
DOM	$55.57	$232	$232
DPL	$67.10	$221	$221
DUQ	$71.15	$217	$217
EKPC	$71.00	$217	$217
JCPL	$36.44	$252	$252
METED	$58.75	$229	$229
PECO	$43.96	$244	$244
PENELEC	$118.00	$170	$170
PEPCO	$53.17	$235	$235
PPL	$45.01	$243	$243
PSEG	$35.07	$253	$253
RECO	$38.53	$249	$249
Average	**$62**	**$226**	**$226**
Std Dev	**$20**	**$20**	**$20**
Std Dev / Average	**33%**	**9%**	**9%**

Combined Cycle			
		Gross CONE	$320
		Net Reactive Service Revenue Offset	$9.18
		Capacity Value (% Nameplate MW)	NA
Zone	Net E&AS* Revenue Offset	Net CONE	Default Net CONE ($/ICAP MW-Day)
AECO	$142.70	$168	$168
AEP	$214.72	$96	$96
APS	$241.90	$69	$69
ATSI	$219.98	$91	$91
BGE	$237.39	$73	$73
COMED	$170.74	$140	$140
DAYTON	$221.05	$90	$90
DEOK	$217.30	$94	$94
DOM	$184.01	$127	$127
DPL	$199.12	$112	$112
DUQ	$212.69	$98	$98
EKPC	$222.55	$88	$88
JCPL	$142.05	$169	$169
METED	$194.20	$117	$117
PECO	$165.61	$145	$145
PENELEC	$270.68	$40	$40
PEPCO	$193.41	$117	$117
PPL	$165.97	$145	$145
PSEG	$140.55	$170	$170
RECO	$144.76	$166	$166
Average	**$195**	**$116**	**$116**
Std Dev	**$36**	**$36**	**$36**
Std Dev / Average	**19%**	**31%**	**31%**

*** Net E&AS Revenue Offset value in tables above does not include reactive services. Reactive services constant is added to Net E&AS to determine Net CONE.**

- PJM's Net CONE estimates by zone illustrate impact of market conditions
- Gross CONE is the same across zones, isolating variability to E&AS estimate
- CC has higher absolute value of variability
- Coefficient of Variation (i.e., ratio of standard deviation to average) is higher for the CC Net CONE
- E&AS offset has a smaller impact on the CT Net CONE because it is a relatively smaller than Gross CONE

[1] Based on the Net CONE calculations presented by PJM on August 2020, 20200814-net-cone-values-and-indicative-eas-offset-workbook-supplemental.xls

By this measure, accuracy of Net CONE is higher for the CT versus the CC

Cost and Estimation Uncertainty

Ancillary services is another area that tends to be overestimated

Percentage of Ancillary Services Provided by Unit/Fuel Type in 2020

Generation Technology	Tier 2 Synchronized Reserve		Nonsynchronized Reserve		Scheduled DASR	
	% by MW	% by Credits	% by MW	% by Credit	% by MW	% by Credit
CT – Natural Gas	37.0%	42.1%	50.6%	58.9%	61.7%	51.7%
CT – Oil	12.3%	16.7%	34.6%	31.1%	18.9%	18.2%
DSR	27.8%	11.2%	0.0%	0.0%	0.0%	0.0%
Combined Cycle	11.7%	21.3%	0.0%	0.0%	2.8%	13.0%
Hydro-Run of River	6.4%	3.2%	14.6%	9.9%	0.0%	0.0%
Hydro – Pumped Storage	0.7%	0.6%	0.1%	0.1%	10.3%	3.6%
CT – Other	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Steam - Coal	3.6%	4.2%	0.0%	0.0%	5.6%	9.0%
RICE – Natural Gas/Other	0.4%	0.4%	0.0%	0.0%	0.4%	1.4%
Steam – Natural Gas	0.1%	0.3%	0.0%	0.0%	0.3%	1.0%
Battery	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fuel Cell	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Nuclear	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Solar	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Wind	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Source: Market Monitor Reports

Batteries coming in as hybrid or stand-alone can address much of PJM's needs

Cost and Estimation Uncertainty

State goals and mandates can and will result in early retirements

Factors Impacting Reference Unit Lifespan

Technical

- Technical life depends on operations and degradation rates
- Combined Cycles are more expensive to operate than Combustion Turbines
- Batteries are particularly sensitive to number of charge/discharge cycles
- Changes in volatility could adversely impact maintenance costs and technical viability

Economic

- Transition to higher renewable integration suppresses natural gas and energy prices
- New renewables could adversely impact scarcity pricing and volatility
- Batteries will suppress volatility, challenging their arbitrage opportunities
- Fossil fuel units may have to retire early

Policy

- Federal and state policies impact build-out and follow-on impacts
- States with Net-Zero goals and 100% RPS requirements may mandate retirement or prevent fossil fuel units from remaining online
- Project lifespans should not extend beyond policy directives/mandates

Projected operations should reflect factors impacting lifespan

Cost and Estimation Uncertainty

Key questions to consider in the life extension assumption

- **Is it realistic to assume a plant can operate 30 years without:**
  - Significant capital investment
  - Major upgrades and maintenance to extend life
  - Refinancing with associated financing costs
- **Are there other factors that need to be considered:**
  - Technical constraints tied to physical limitations
  - Economic uncertainty tied to market transformation
  - Policy trends
- **How does this correspond to state policies that would limit**
  - Repowering
  - Permits
  - Emissions
  - Continued operations

The reality is that many of these plants are stranded before they are even built

Cost and Estimation Uncertainty

The energy offset is uncertain and should not dictate parameters

As noted by the U.S. Court of Appeals:

"Combined cycle plants are more reliant on energy market revenues to justify construction. Those energy market revenues—included in the EAS Revenue Estimate— are often considered more difficult to estimate than the construction costs that also factor into the net CONE. Accordingly, any mis-estimation of energy market revenues has a larger impact on the accuracy of a combined cycle plant's net CONE than on a combustion turbine plant's."

- United States Court of Appeals FOR THE DISTRICT OF COLUMBIA CIRCUIT, Argued April 6, 2021, Decided July 9, 2021, No. 20-1212 DELAWARE DIVISION OF THE PUBLIC ADVOCATE, ET AL., PETITIONERS v. FEDERAL ENERGY REGULATORY COMMISSION, RESPONDENT PJM INTERCONNECTION, L.L.C., INTERVENOR On Petition for Review of Orders of the Federal Energy Regulatory Commission, p. 10.

Energy revenues are even more difficult to estimate due to market transition

Analysis in Support of the Appropriate Reference Unit

VRR CURVE

VRR Curve

Brattle is looking to steepen the VRR Curve

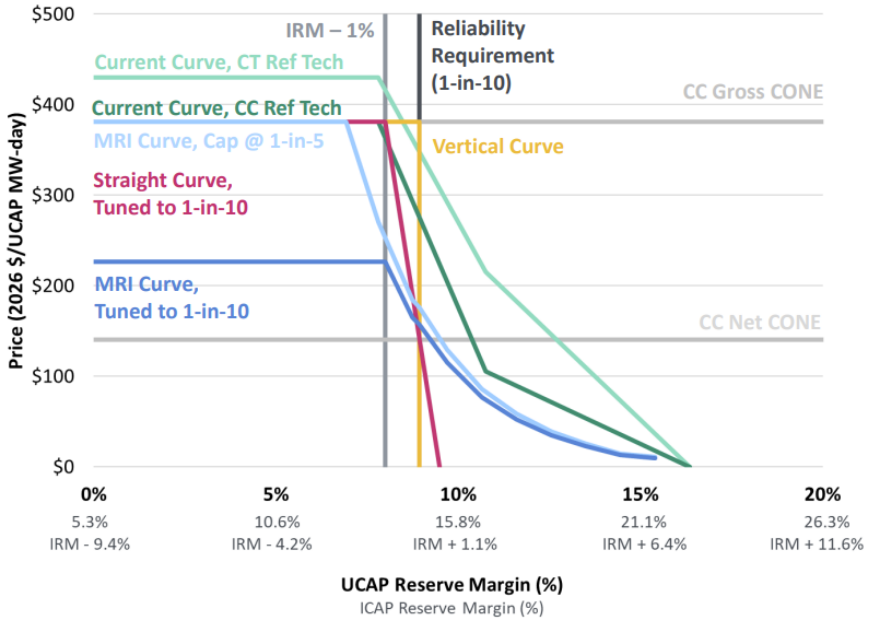
OVERVIEW

Initial range of assessed VRR parameters

We have not yet developed a specific VRR curve recommendation

Directionally, we recommend to adopt a CC-based Net CONE and a steeper VRR curve shape

Illustrative Range of Curves Evaluated



Note: Current Curve, CT has price cap at 1.5 x Net CONE; Current Curve, CC has cap at CC Gross CONE (greater than 1.5 x CC Net CONE); Straight curve, tuned to 1-in-10 BRA LOLE, passes through (Reliability Requirement, CC Net CONE); MRI Curve, tuned to 1-in-10 LOLE is calculated as the avoided expected unserved energy (EUE) per UCAP MW of capacity added, inflated by a $/MWh multiplier to translate into units of capacity price. Multiplier chosen to achieve 1-in-10 BRA LOLE. Gross and Net CONE values are from 2023-2024 BRA Default MOPR, converted to $2026 using a 2.7% inflation rate.

brattle.com | 6

Source: The Brattle Group, Fifth Review of the Variable Resource Requirement Curve Presented by Samuel Newell Michael Hagerty Travis Carless, Preliminary Assessment of the VRR Curve Shape Presented to PJM Market Implementation Committee, December 8, 2021, p. 6.

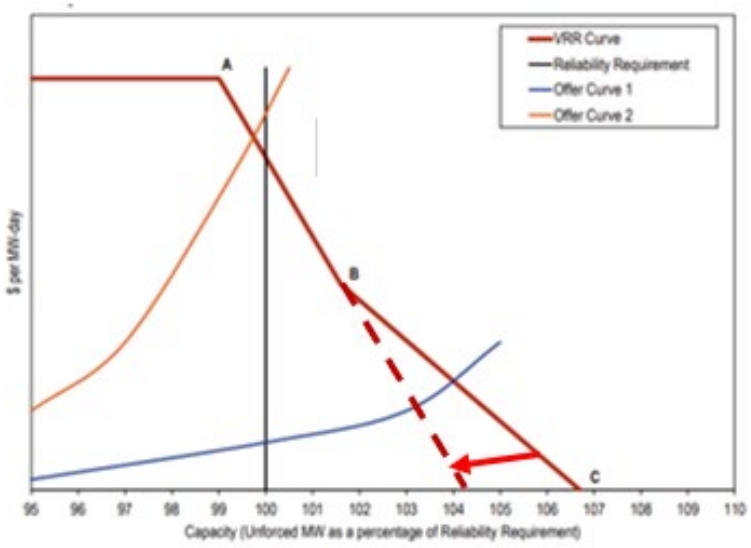
The rationale seems to be based on historical procurement levels

Uncertainty would justify extending the curve out to the right

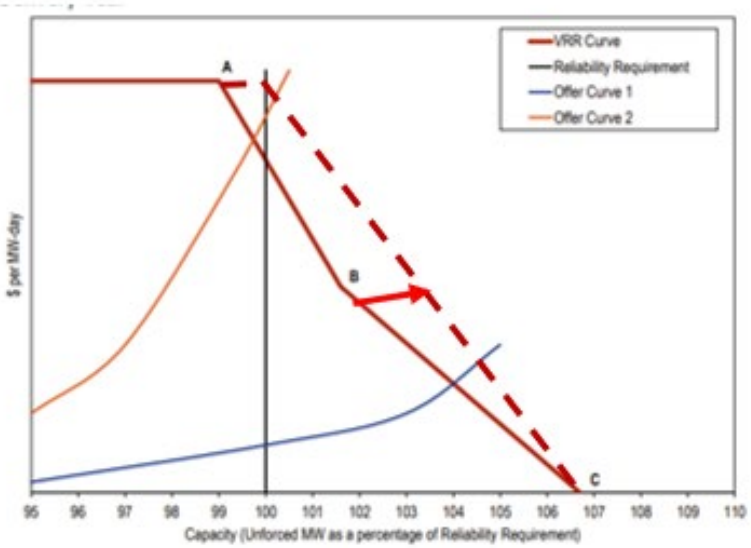
PJM

Alternative Ways to Steepen the VRR Curve

Alternative 1



Alternative 2



Regardless, a clear rationale for changing the parameters is needed

ENERGYZT

VRR Curve

The Reference Unit does not need to have the lowest Net CONE

As the U.S. Court of Appeals:

"The Commission reasonably determined that an oversupplying combustion turbine plant-based VRR Curve, at a modest cost increase, was compatible with consumer interests because it ensured reliability more consistently than a combined cycle plant-based VRR Curve."

- United States Court of Appeals FOR THE DISTRICT OF COLUMBIA CIRCUIT, Argued April 6, 2021, Decided July 9, 2021, No. 20-1212 DELAWARE DIVISION OF THE PUBLIC ADVOCATE, ET AL., PETITIONERS v. FEDERAL ENERGY REGULATORY COMMISSION, RESPONDENT PJM INTERCONNECTION, L.L.C., INTERVENOR On Petition for Review of Orders of the Federal Energy Regulatory Commission, p. 12, Footnote 6.

The Court supported FERC determination of an outcome that is just and reasonable

Analysis in Support of the Appropriate Reference Unit

CONCLUSION

Conclusion

A lower Net CONE does not ensure reliability

- Choosing the resource solely based on the "lowest" *estimated* Net CONE is not prudent
  - Focuses on cost as the only characteristic versus operational capability
  - Gives undue emphasis to estimated and uncertain E&AS offsets
  - Could create needless barriers to entry for other technologies
- FERC and the U.S. Court of Appeals found a number of reasons why a *higher cost* combustion turbine can be the Reference Unit:
  - Combustion Turbine is reflective of resource adequacy and reliability
    - Less costly up-front capital
    - Quicker to market
    - Rapidly meets changes in demand
    - Satisfies the Reliability Requirement
  - Combined cycle was more uncertain
    - More dependent on estimated E&AS offsets
    - Negative impacts from shifting plant from year to year

Transition to a new energy economy should allow new technologies to compete

Conclusion

Why add another change to the market?

- Markets already are facing significant uncertainty
  - Policy pressures to change the generation mix
  - Transformation to a decarbonized grid
  - Implementation of new technologies
  - Volatile natural gas prices
- RPM market rules are changing dramatically
  - Elimination of the MOPR
  - ELCC
  - MSOC Uncertainty
  - 10% adder removed for the first time in PJM history
  - EAS based on backward-looking (6/2022) or forward-looking (12/2022)?
- Higher levels of estimation errors
  - Gross CONE estimates
  - E&AS Estimates
  - Inflation
- Any justification and support for changing the VRR Curve should be forward-looking and account for uncertainty, and not try to correct for historical results

Tightening the VRR Curve and choosing a different technology would be a mistake