

# Fifth Review of the Variable Resource Requirement Curve

NEAR FINAL RESULTS OF VRR CURVE ANALYSIS

PRESENTED BY

Kathleen Spees  
Samuel Newell  
Andrew Thompson  
Xander Bartone

PRESENTED TO

PJM Market Implementation  
Committee

MARCH 25, 2022



---

# Recommendations

# Updated recommendations

---

## Recommendations for RPM affecting the application of the VRR curve

- Eliminate over-forecast bias in the load forecast
- Improve accuracy, transparency, and consistency in capacity supply and demand accounting, particularly for winter

**Recommendations for the VRR curve** to achieve satisfactory reserve margins and mitigate uncertainties/volatility in prices and quantities

- Adopt a gas-fired Combined Cycle (CC) plant as the reference technology
- Balance competing objectives through adjustments to the system-wide VRR curve
  - Maintain a high enough price cap given Net CONE uncertainties; we suggest raising the cap to  $\text{Max}\{1.75 \times \text{Net CONE}, \text{Gross CONE}\}$ , changing the current Net CONE multiple from 1.5 to 1.75 even though Gross CONE would set the price cap at current E&AS
  - Consider a steeper curve to mitigate high uncertainty in Net CONE
  - Defer considering any additional left-shifting in the BRA VRR curve
- For the LDAs
  - Consider MRI-based demand curves (and associated market clearing) to moderate price volatility and manage reliability needs
  - In select LDAs (PSEG, ComEd) most affected by environmental regulations, continue to work with states and monitor whether gas-fired plants can be built; if not, identify a clean reference technology
  - For all LDAs, set Net CONE and price cap at maximum of local and all parent LDAs' values

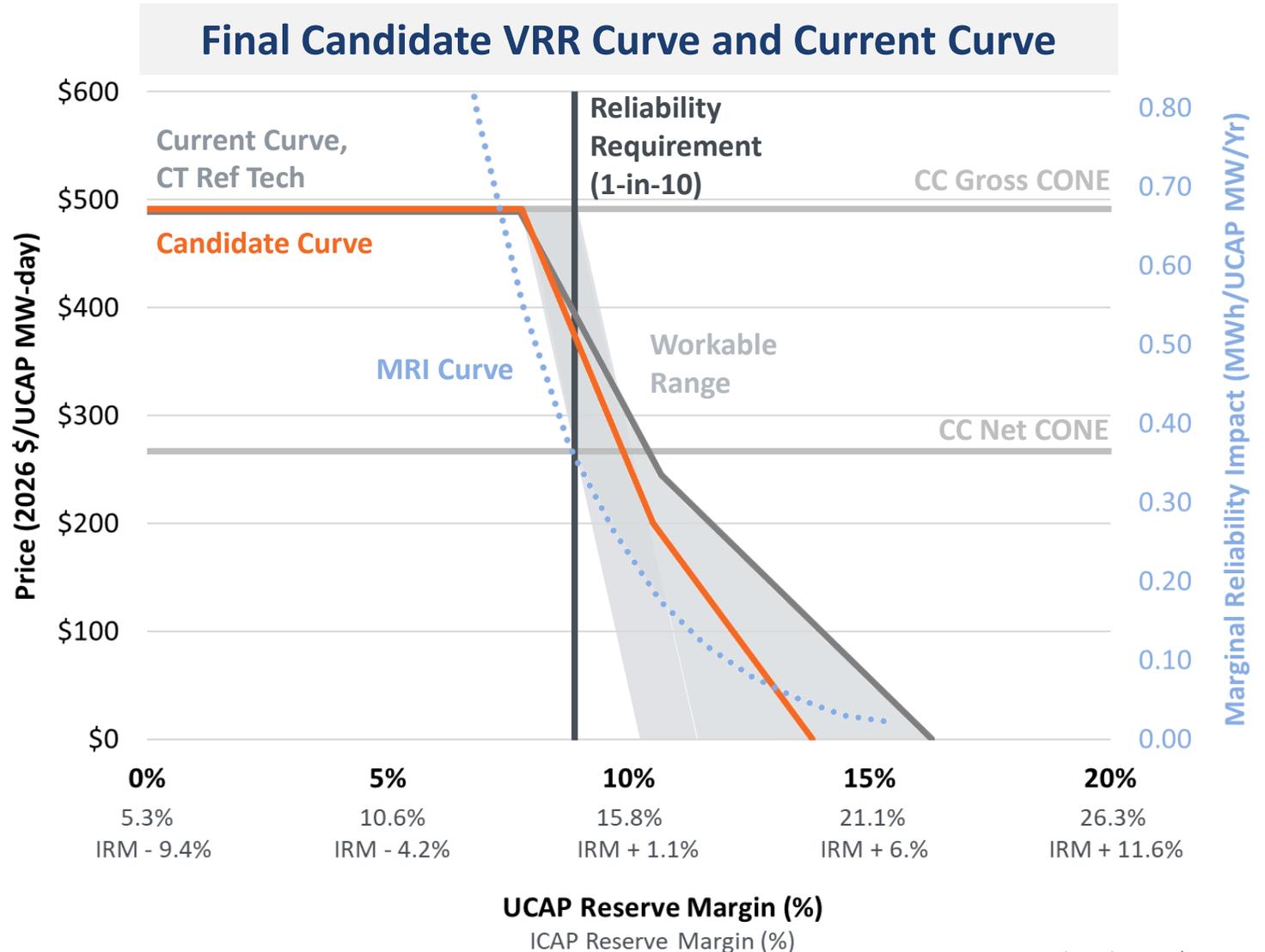
**Broaden the scope of the next Quadrennial Review to its original, more comprehensive scope as an RPM review given the substantial need for broad reforms over the coming decade**

# Candidate VRR curve and “workable range”

**We recommend a candidate VRR curve that is moderately steeper than the current VRR curve**

- Modest reduction to procurement levels, but reliability estimated to remain above 1-in-10
- Steeper shape continues to manage Net CONE uncertainty, even with a lower Net CONE value based on CC

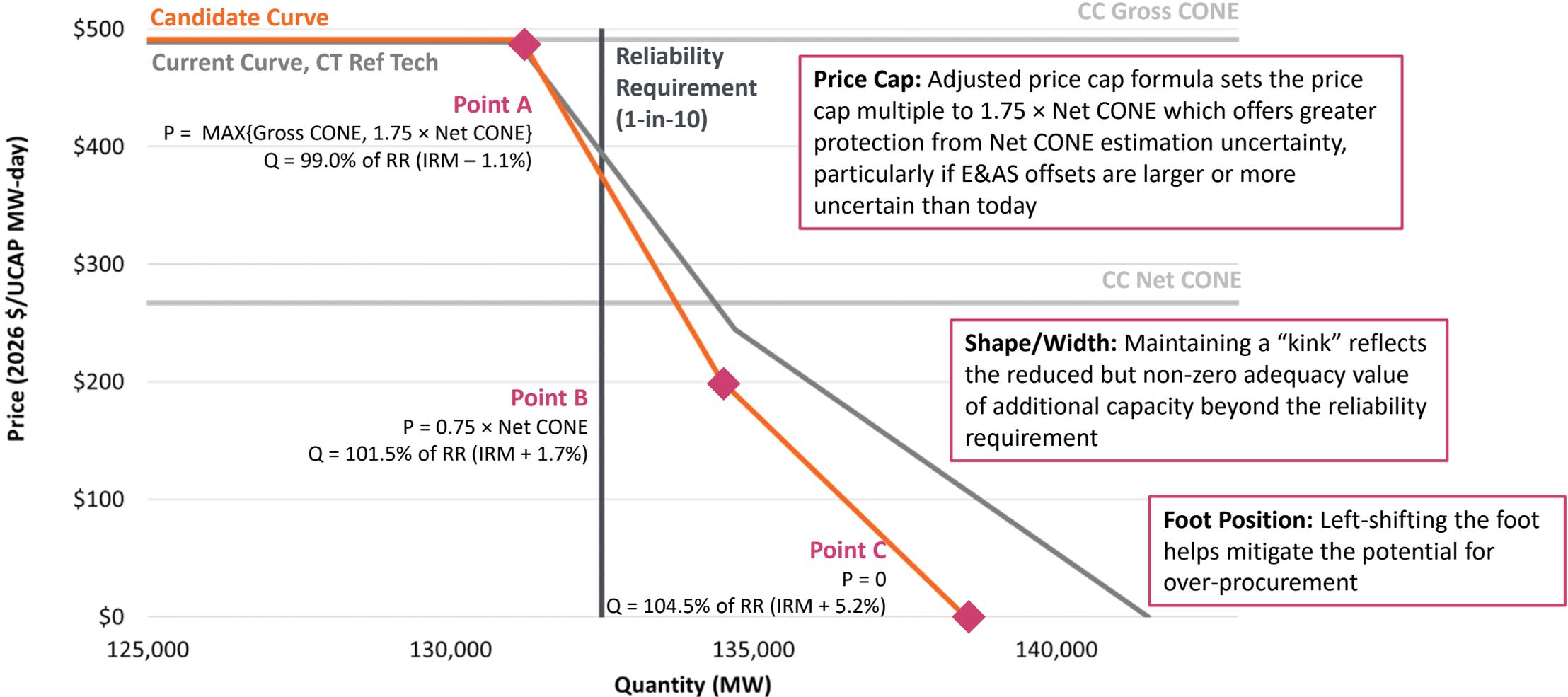
**We also present modeling results from several alternative VRR curves in the “workable range” that offer a different balance of performance tradeoffs**



---

# Performance of the Candidate Curve

# Candidate VRR curve formula



Note: Current Curve, CT has a price cap at  $1.5 \times \text{CT Net CONE}$  (greater than CC Gross CONE); Candidate Curve has a price cap at CC Gross CONE (greater than  $1.75 \times \text{CC Net CONE}$ ). The VRR curve price caps appear equal because  $1.5 \times \text{CT Net CONE}$  and CC Gross CONE are very similar numbers by coincidence. Gross and Net CONE values are in 2026 dollars and are from the concurrent Brattle CONE study.

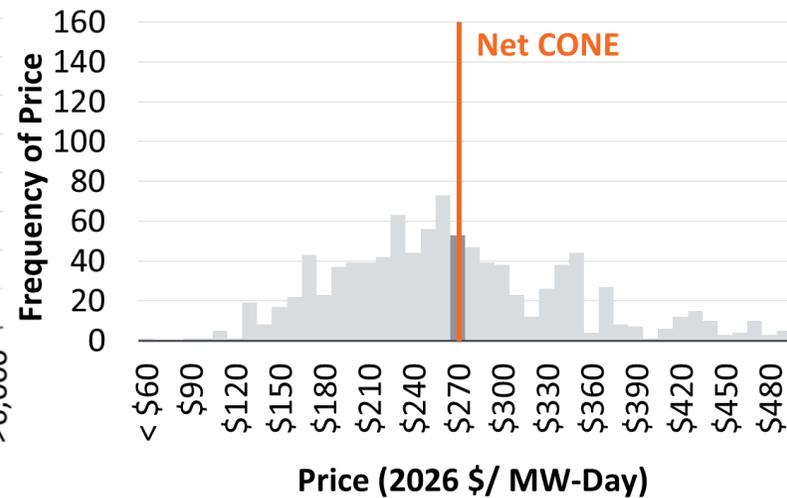
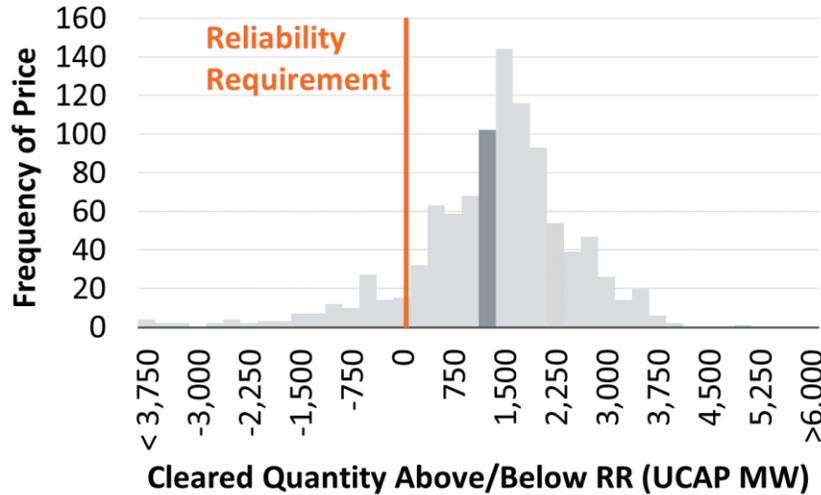
# Performance managing price risks and excess procurement

## Candidate VRR Curve Performance:

- Reduces expected procurement beyond the Reliability Requirement by 812 UCAP MW on average
- Maintains an expected LOLE of 0.074, somewhat better than current reliability standard
- Modest increase in price volatility compared to current curve

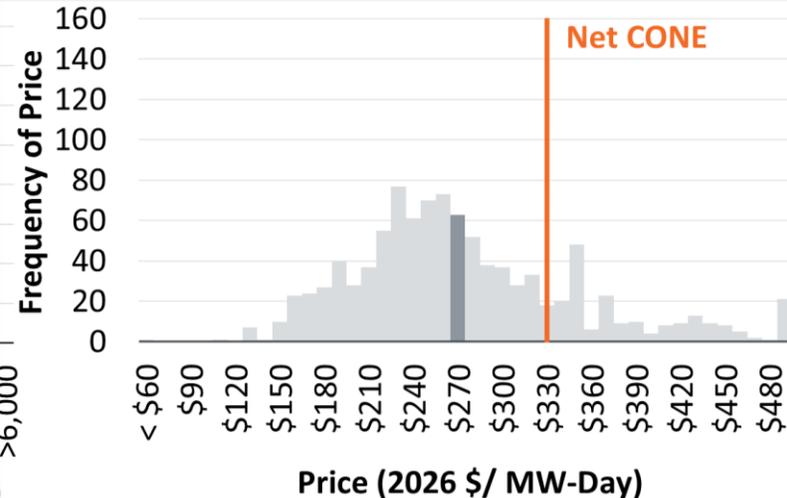
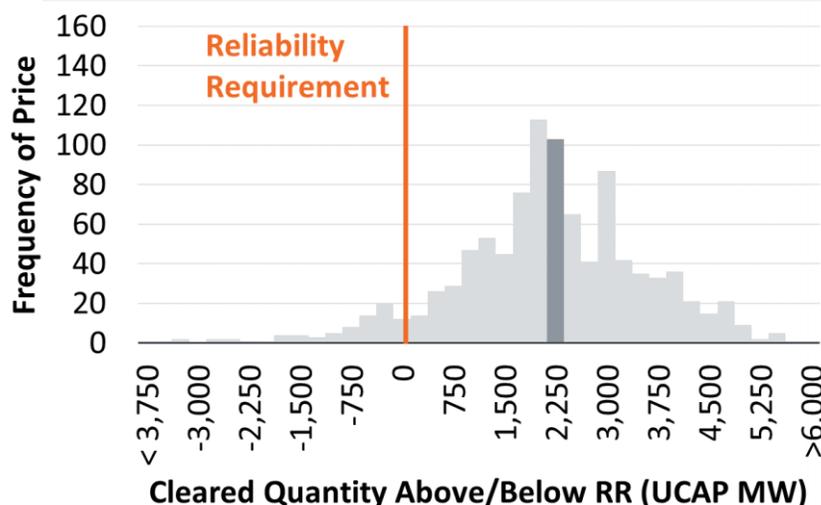
Note: Histograms are reflective of results after the BRA, created from the last 1,000 model draws. Historical 2009-2022 RTO clearing price volatility is \$48.59.

### Candidate Curve, CC Reference Technology



Expected LOLE: 0.074  
 Avg. excess: 1,220 UCAP MW  
 Stdev. of price: \$87/MW-day  
 Freq. below RR: 11.4%  
 Freq. at cap: 3.1%

### Current Curve, CT Reference Technology



Expected LOLE: 0.059  
 Avg. excess: 2,032 UCAP MW  
 Stdev. of price: \$76/MW-day  
 Freq. below RR: 7.9%  
 Freq. at cap: 1.8%

# Performance managing Net CONE uncertainties

Demand Curve	Measured After the 3-Year Forward BRA								
	Price			Reliability				Cost	
	Average	Standard Deviation	Frequency at Cap	Average LOLE	Average Excess (Deficit)	Average Excess (Deficit)	Frequency Below Target	Frequency Below IRM - 1%	Average Procurement Cost
	(\$/MW-d)	(\$/MW-d)	(%)	(events/yr)	(MW)	(IRM + X %)	(%)	(%)	(\$ mln/yr)
<b>Current Curve, CT</b>									
True Net CONE = 0.6 x CC Net CONE	\$160	\$53	0.0%	0.026	4,547	4.0%	0.0%	0.0%	\$8,030
<b>True Net CONE = CC</b>	<b>\$267</b>	<b>\$76</b>	<b>1.8%</b>	<b>0.059</b>	<b>2,032</b>	<b>1.8%</b>	<b>7.9%</b>	<b>2.1%</b>	<b>\$13,170</b>
True Net CONE = CT	\$326	\$87	8.1%	0.086	913	0.8%	24.0%	9.5%	\$15,940
True Net CONE = 1.4 x CC Net CONE	\$374	\$88	18.6%	0.119	-53	0.0%	44.0%	21.8%	\$18,129
<b>Current Curve, CC</b>									
True Net CONE = 0.6 x CC Net CONE	\$160	\$52	0.0%	0.034	3,717	3.2%	0.0%	0.0%	\$7,979
<b>True Net CONE = CC</b>	<b>\$267</b>	<b>\$83</b>	<b>2.5%</b>	<b>0.070</b>	<b>1,435</b>	<b>1.3%</b>	<b>10.2%</b>	<b>3.3%</b>	<b>\$13,119</b>
True Net CONE = CT	\$326	\$94	9.6%	0.096	498	0.5%	29.5%	11.4%	\$15,898
True Net CONE = 1.4 x CC Net CONE	\$374	\$94	20.6%	0.128	-347	-0.3%	48.1%	25.4%	\$18,096
<b>Candidate Curve</b>									
True Net CONE = 0.6 x CC Net CONE	\$160	\$58	0.0%	0.043	2,862	2.5%	0.0%	0.0%	\$7,940
<b>True Net CONE = CC</b>	<b>\$267</b>	<b>\$87</b>	<b>3.1%</b>	<b>0.074</b>	<b>1,220</b>	<b>1.1%</b>	<b>11.4%</b>	<b>3.9%</b>	<b>\$13,104</b>
True Net CONE = CT	\$326	\$96	10.6%	0.099	375	0.4%	31.3%	11.9%	\$15,887
True Net CONE = 1.4 x CC Net CONE	\$374	\$96	22.2%	0.131	-423	-0.3%	50.0%	25.9%	\$18,088

Candidate Curve provides acceptable reliability even if Net CONE is substantially underestimated

Candidate Curve will reduce the potential for over-procurement by bringing in the "foot", even if Net CONE is substantially over-estimated

---

# Alternative Curves in the “Workable Range”

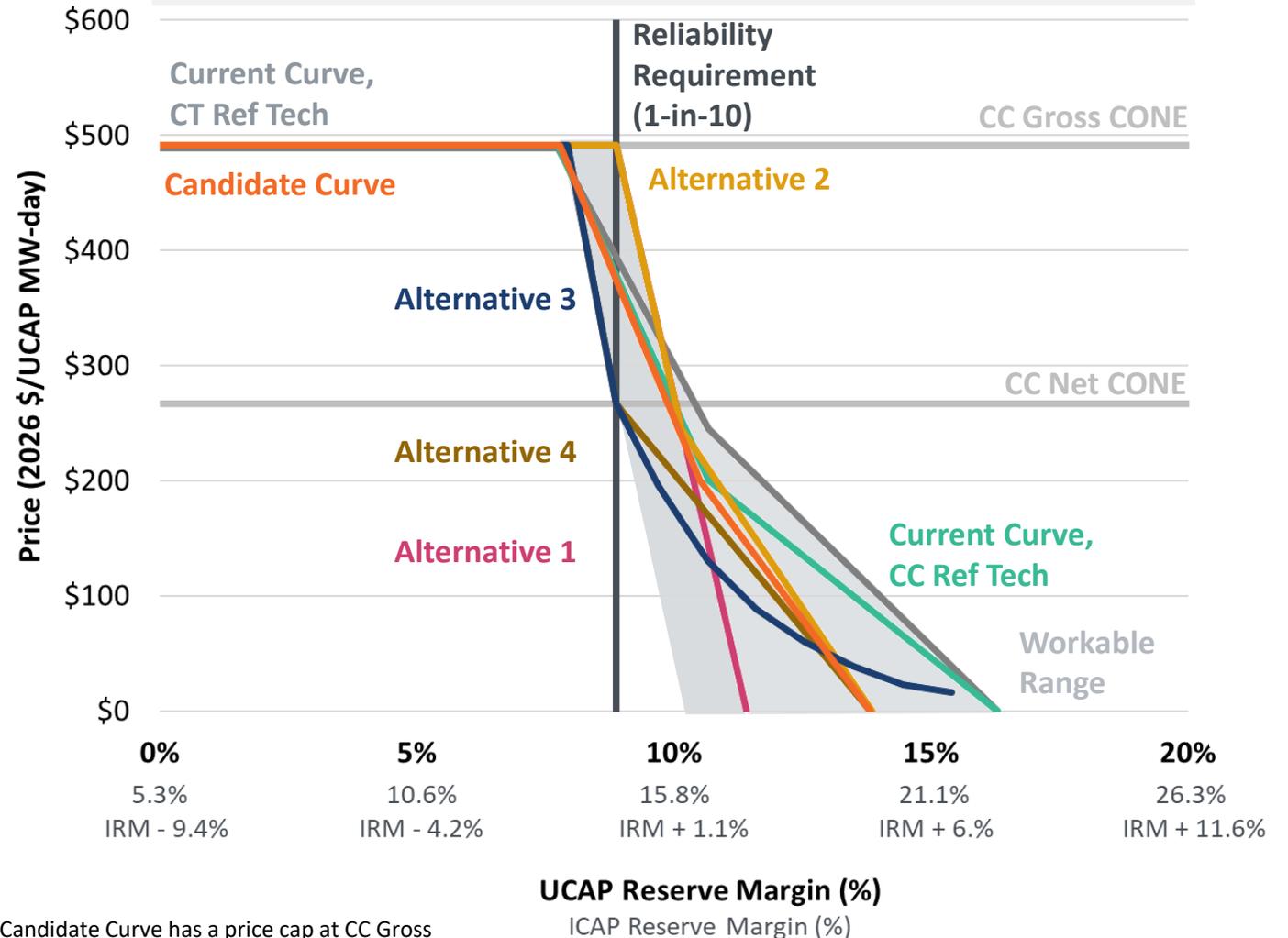
# Several alternative curves are likely in a well-performing workable range, but with a differing balance of tradeoffs

We also offer several alternative curves that are in the “workable range” that align with design objectives but offer differing performance tradeoffs

## Description:

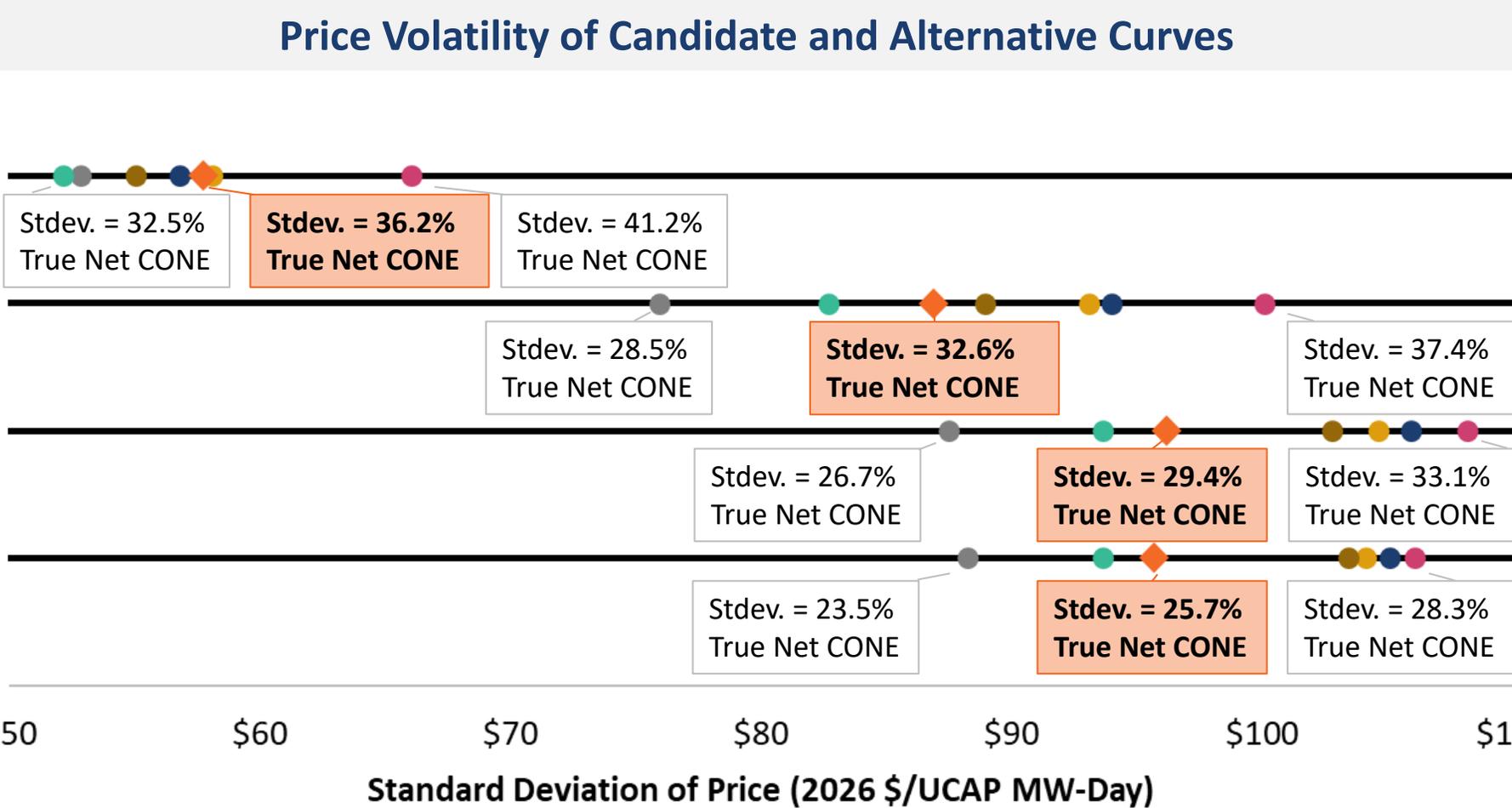
- Alternative 1: steeper straight curve
- Alternative 2: steeper kinked curve
- Alternative 3: based on the MRI
- Alternative 4: straight-line MRI curve

### Final Candidate VRR Curve and Alternative Curves



Note: Current Curve, CT has a price cap at  $1.5 \times$  CT Net CONE (greater than CC Gross CONE); Candidate Curve has a price cap at CC Gross CONE (greater than  $1.75 \times$  CC Net CONE). The VRR curve price caps appear equal because  $1.5 \times$  CT Net CONE and CC Gross CONE are very similar numbers by coincidence. Gross and Net CONE values are in 2026 dollars and are from the concurrent Brattle CONE study.

# Performance tradeoffs: price volatility



- Current Curve, CC Ref Tech
- Current Curve, CT Ref Tech
- Candidate Curve
- Alternative 1
- Alternative 2
- Alternative 3
- Alternative 4

Note: Historical 2009-2022 RTO clearing price volatility is \$48.59.

# Performance tradeoffs: excess or deficit procurement

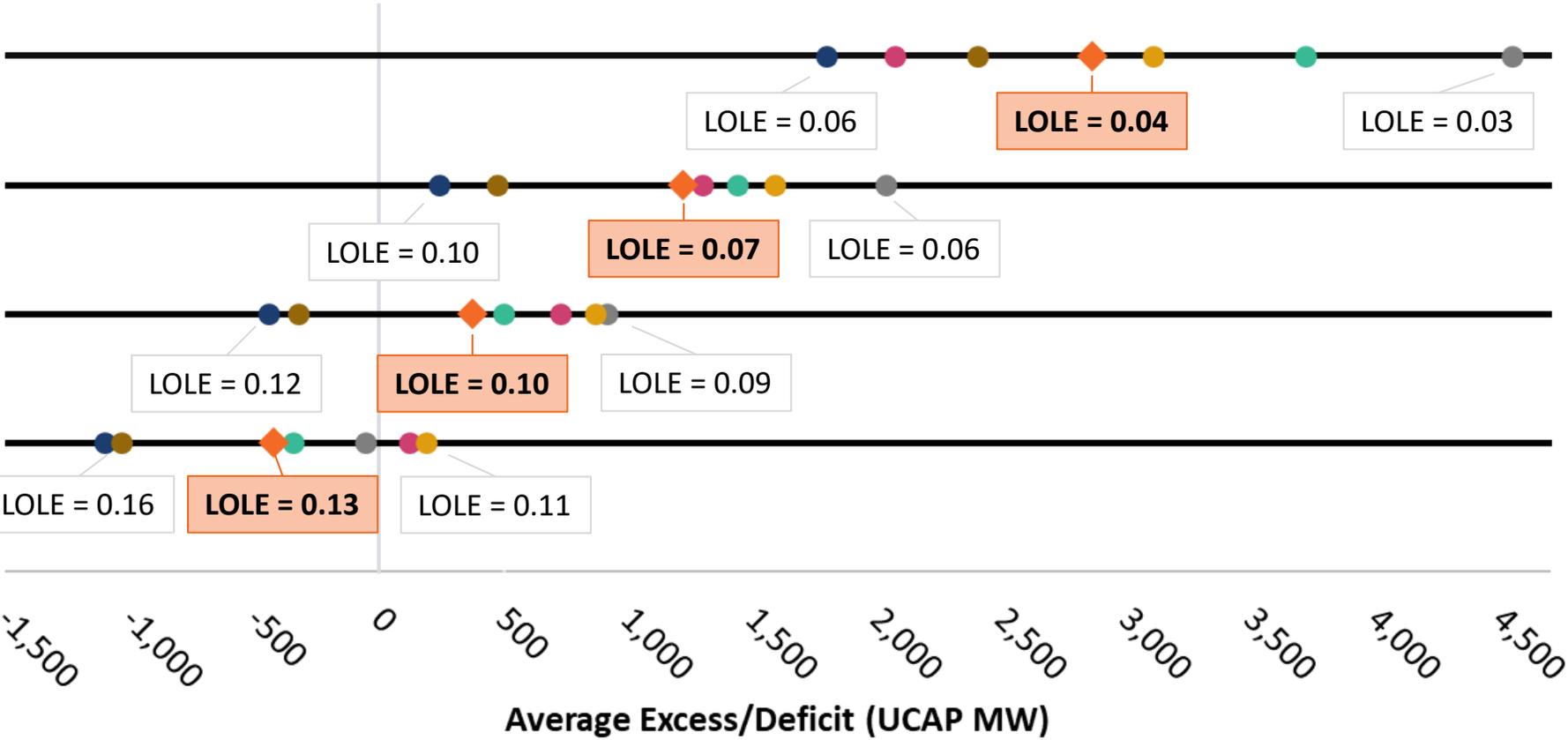
Average Excess/Deficit Procurement of Candidate and Alternative Curves

True Net CONE = 0.6 × CC Net CONE (\$160/UCAP MW-Day)

True Net CONE = CC (\$267/UCAP MW-Day)

True Net CONE = CT (\$326/UCAP MW-Day)

True Net CONE = 1.4 × CC Net CONE (\$374/UCAP MW-Day)



- Current Curve, CC Ref Tech
- Current Curve, CT Ref Tech
- Candidate Curve
- Alternative 1
- Alternative 2
- Alternative 3
- Alternative 4

# Stakeholder input to inform the Quadrennial Review

Provide input on near final results by **April 1** to [Melissa.Pilong@pjm.com](mailto:Melissa.Pilong@pjm.com) or [Gary.Helm@pjm.com](mailto:Gary.Helm@pjm.com)



# Contact Information

---



Sam Newell

PRINCIPAL | BOSTON

[Sam.Newell@brattle.com](mailto:Sam.Newell@brattle.com)

+1 (617) 234-5725



Kathleen Spees

PRINCIPAL | WASHINGTON DC

[Kathleen.Spees@brattle.com](mailto:Kathleen.Spees@brattle.com)

+1 (202) 419-3390



Andrew Thompson

ELECTRICITY MODELING SPECIALIST |  
MADRID

[Andrew.Thompson@brattle.com](mailto:Andrew.Thompson@brattle.com)

+34.1.910.487121

---

# Appendix

# Results of Base Case

Demand Curve	Measured After the 3-Year Forward BRA									Measured After the Last Incremental Auction						
	Price			Reliability					Cost			Reliability				
	Average	Standard	Frequency	Average	Average	Average	Frequency	Frequency	Average	Average	Average	Frequency	Frequency			
(\$/MW-d)	Deviation	at Cap	LOLE	Excess	Excess	Below	Below	Procurement	LOLE	Excess	Excess	Below	Below			
	(\$/MW-d)	(%)	(events/yr)	(MW)	(Deficit)	(Deficit)	Target	IRM - 1%	Cost	(events/yr)	(MW)	(Deficit)	Target	IRM - 1%		
					(IRM + X %)	(%)	(%)	(\$ mln/yr)			(IRM + X %)	(%)	(%)			
Current Curve, CT	\$267	\$76	1.8%	0.059	2,032	1.8%	7.9%	2.1%	\$13,170	0.057	2,260	2.0%	8.0%	3.2%		
Current Curve, CC	\$267	\$83	2.5%	0.070	1,435	1.3%	10.2%	3.3%	\$13,119	0.068	1,669	1.5%	10.4%	4.4%		
<b>Candidate Curve</b>	<b>\$267</b>	<b>\$87</b>	<b>3.1%</b>	<b>0.074</b>	<b>1,220</b>	<b>1.1%</b>	<b>11.4%</b>	<b>3.9%</b>	<b>\$13,104</b>	<b>0.071</b>	<b>1,458</b>	<b>1.3%</b>	<b>12.4%</b>	<b>5.1%</b>		
Alternative 1	\$267	\$100	6.1%	0.070	1,296	1.1%	6.1%	2.8%	\$13,134	0.068	1,534	1.4%	8.9%	3.6%		
Alternative 2	\$267	\$93	5.6%	0.065	1,587	1.4%	5.6%	2.4%	\$13,148	0.064	1,820	1.6%	8.2%	3.2%		
Alternative 3	\$267	\$94	6.0%	0.098	243	0.2%	37.7%	6.0%	\$13,016	0.094	517	0.5%	22.0%	8.8%		
Alternative 4	\$267	\$89	5.5%	0.093	472	0.4%	36.1%	5.5%	\$13,030	0.089	738	0.7%	20.5%	8.1%		

Demand Curve	Measured After the 3-Year Forward BRA								Measured After the Last Incremental Auction					
	Price			Reliability				Cost	Reliability					
	Average	Standard Deviation	Frequency at Cap	Average LOLE	Average Excess (Deficit)	Average Excess (Deficit)	Frequency Below Target	Frequency Below IRM - 1%	Average Procurement Cost	Average LOLE	Average Excess (Deficit)	Average Excess (Deficit)	Frequency Below Target	Frequency Below IRM - 1%
	(\$/MW-d)	(\$/MW-d)	(%)	(events/yr)	(MW)	(IRM + X %)	(%)	(%)	(\$ mln/yr)	(events/yr)	(MW)	(IRM + X %)	(%)	(%)
<b>Current Curve, CT</b>														
True Net CONE = 0.6 x CC Net CONE	\$160	\$53	0.0%	0.026	4,547	4.0%	0.0%	0.0%	\$8,030	0.024	4,900	4.3%	0.2%	0.0%
<b>True Net CONE = CC</b>	<b>\$267</b>	<b>\$76</b>	<b>1.8%</b>	<b>0.059</b>	<b>2,032</b>	<b>1.8%</b>	<b>7.9%</b>	<b>2.1%</b>	<b>\$13,170</b>	<b>0.057</b>	<b>2,260</b>	<b>2.0%</b>	<b>8.0%</b>	<b>3.2%</b>
True Net CONE = CT	\$326	\$87	8.1%	0.086	913	0.8%	24.0%	9.5%	\$15,940	0.084	1,124	1.0%	21.0%	11.0%
True Net CONE = 1.4 x CC Net CONE	\$374	\$88	18.6%	0.119	-53	0.0%	44.0%	21.8%	\$18,129	0.115	184	0.2%	35.2%	21.4%
<b>Current Curve, CC</b>														
True Net CONE = 0.6 x CC Net CONE	\$160	\$52	0.0%	0.034	3,717	3.2%	0.0%	0.0%	\$7,979	0.032	4,070	3.5%	0.5%	0.2%
<b>True Net CONE = CC</b>	<b>\$267</b>	<b>\$83</b>	<b>2.5%</b>	<b>0.070</b>	<b>1,435</b>	<b>1.3%</b>	<b>10.2%</b>	<b>3.3%</b>	<b>\$13,119</b>	<b>0.068</b>	<b>1,669</b>	<b>1.5%</b>	<b>10.4%</b>	<b>4.4%</b>
True Net CONE = CT	\$326	\$94	9.6%	0.096	498	0.5%	29.5%	11.4%	\$15,898	0.093	724	0.7%	24.3%	12.8%
True Net CONE = 1.4 x CC Net CONE	\$374	\$94	20.6%	0.128	-347	-0.3%	48.1%	25.4%	\$18,096	0.123	-97	0.0%	39.1%	23.1%
<b>Candidate Curve</b>														
True Net CONE = 0.6 x CC Net CONE	\$160	\$58	0.0%	0.043	2,862	2.5%	0.0%	0.0%	\$7,940	0.040	3,212	2.8%	0.9%	0.3%
<b>True Net CONE = CC</b>	<b>\$267</b>	<b>\$87</b>	<b>3.1%</b>	<b>0.074</b>	<b>1,220</b>	<b>1.1%</b>	<b>11.4%</b>	<b>3.9%</b>	<b>\$13,104</b>	<b>0.071</b>	<b>1,458</b>	<b>1.3%</b>	<b>12.4%</b>	<b>5.1%</b>
True Net CONE = CT	\$326	\$96	10.6%	0.099	375	0.4%	31.3%	11.9%	\$15,887	0.096	605	0.6%	25.2%	13.2%
True Net CONE = 1.4 x CC Net CONE	\$374	\$96	22.2%	0.131	-423	-0.3%	50.0%	25.9%	\$18,088	0.126	-170	-0.1%	40.1%	23.5%
<b>Alternative 1</b>														
True Net CONE = 0.6 x CC Net CONE	\$160	\$66	0.0%	0.053	2,067	1.8%	0.0%	0.0%	\$7,912	0.049	2,413	2.1%	1.1%	0.4%
<b>True Net CONE = CC</b>	<b>\$267</b>	<b>\$100</b>	<b>6.1%</b>	<b>0.070</b>	<b>1,296</b>	<b>1.1%</b>	<b>6.1%</b>	<b>2.8%</b>	<b>\$13,134</b>	<b>0.068</b>	<b>1,534</b>	<b>1.4%</b>	<b>8.9%</b>	<b>3.6%</b>
True Net CONE = CT	\$326	\$108	15.6%	0.088	729	0.7%	15.6%	9.1%	\$15,949	0.086	934	0.8%	19.3%	10.0%
True Net CONE = 1.4 x CC Net CONE	\$374	\$106	29.6%	0.110	120	0.1%	29.6%	17.1%	\$18,179	0.107	332	0.3%	30.6%	17.7%
<b>Alternative 2</b>														
True Net CONE = 0.6 x CC Net CONE	\$160	\$58	0.0%	0.040	3,106	2.7%	0.0%	0.0%	\$7,955	0.037	3,456	3.0%	0.7%	0.2%
<b>True Net CONE = CC</b>	<b>\$267</b>	<b>\$93</b>	<b>5.6%</b>	<b>0.065</b>	<b>1,587</b>	<b>1.4%</b>	<b>5.6%</b>	<b>2.4%</b>	<b>\$13,148</b>	<b>0.064</b>	<b>1,820</b>	<b>1.6%</b>	<b>8.2%</b>	<b>3.2%</b>
True Net CONE = CT	\$326	\$105	14.9%	0.085	869	0.8%	14.9%	8.4%	\$15,958	0.083	1,071	1.0%	18.0%	9.8%
True Net CONE = 1.4 x CC Net CONE	\$374	\$104	29.4%	0.109	189	0.2%	29.4%	17.1%	\$18,184	0.106	398	0.4%	29.7%	17.5%
<b>Alternative 3</b>														
True Net CONE = 0.6 x CC Net CONE	\$160	\$57	0.0%	0.061	1,796	1.6%	2.4%	0.0%	\$7,875	0.056	2,148	1.9%	2.0%	0.9%
<b>True Net CONE = CC</b>	<b>\$267</b>	<b>\$94</b>	<b>6.0%</b>	<b>0.098</b>	<b>243</b>	<b>0.2%</b>	<b>37.7%</b>	<b>6.0%</b>	<b>\$13,016</b>	<b>0.094</b>	<b>517</b>	<b>0.5%</b>	<b>22.0%</b>	<b>8.8%</b>
True Net CONE = CT	\$326	\$106	16.0%	0.124	-442	-0.4%	62.1%	16.0%	\$15,801	0.119	-162	-0.1%	37.7%	19.5%
True Net CONE = 1.4 x CC Net CONE	\$374	\$105	30.6%	0.156	-1,099	-0.9%	78.4%	30.6%	\$18,008	0.148	-789	-0.6%	51.9%	30.8%
<b>Alternative 4</b>														
True Net CONE = 0.6 x CC Net CONE	\$160	\$55	0.0%	0.051	2,402	2.1%	1.9%	0.0%	\$7,908	0.047	2,754	2.4%	1.2%	0.5%
<b>True Net CONE = CC</b>	<b>\$267</b>	<b>\$89</b>	<b>5.5%</b>	<b>0.093</b>	<b>472</b>	<b>0.4%</b>	<b>36.1%</b>	<b>5.5%</b>	<b>\$13,030</b>	<b>0.089</b>	<b>738</b>	<b>0.7%</b>	<b>20.5%</b>	<b>8.1%</b>
True Net CONE = CT	\$326	\$103	15.2%	0.121	-327	-0.3%	60.8%	15.2%	\$15,809	0.116	-51	0.0%	36.7%	18.5%
True Net CONE = 1.4 x CC Net CONE	\$374	\$103	29.8%	0.154	-1,035	-0.9%	77.9%	29.8%	\$18,013	0.146	-728	-0.6%	51.6%	30.3%