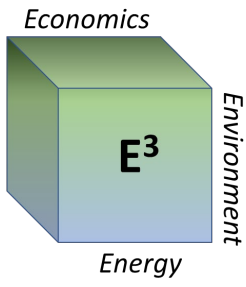


Winter Storm Elliot PJM Performance

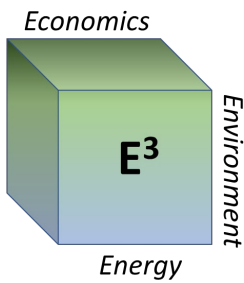
Paul M. Sotkiewicz, Ph.D.

June 14, 2023

ESIG 2023 Meteorology & Market Design for Grid Services Workshop



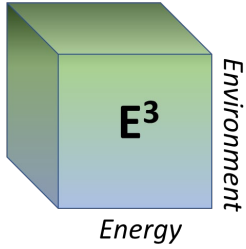
What We Knew Going into Operating Days 12/23-12/24



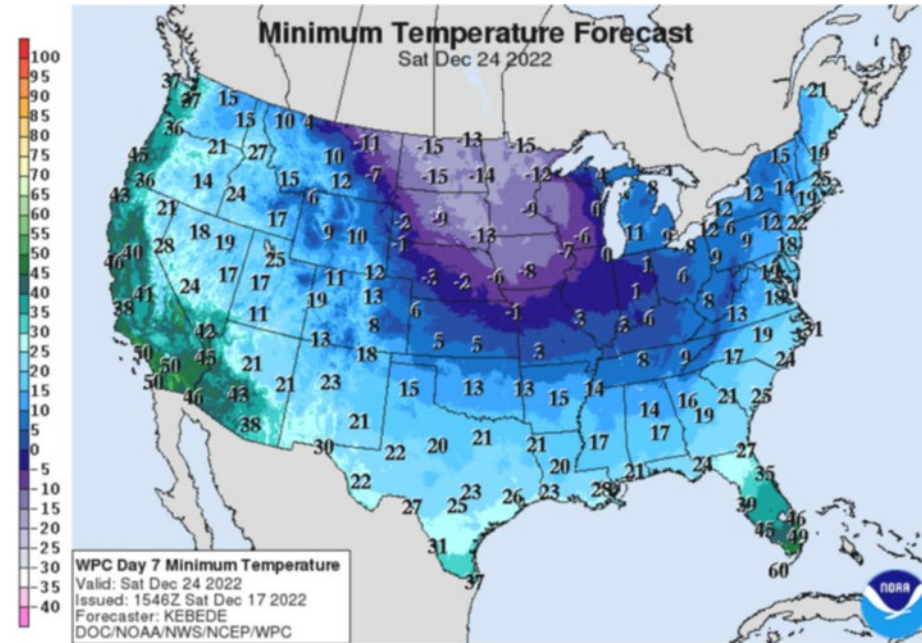
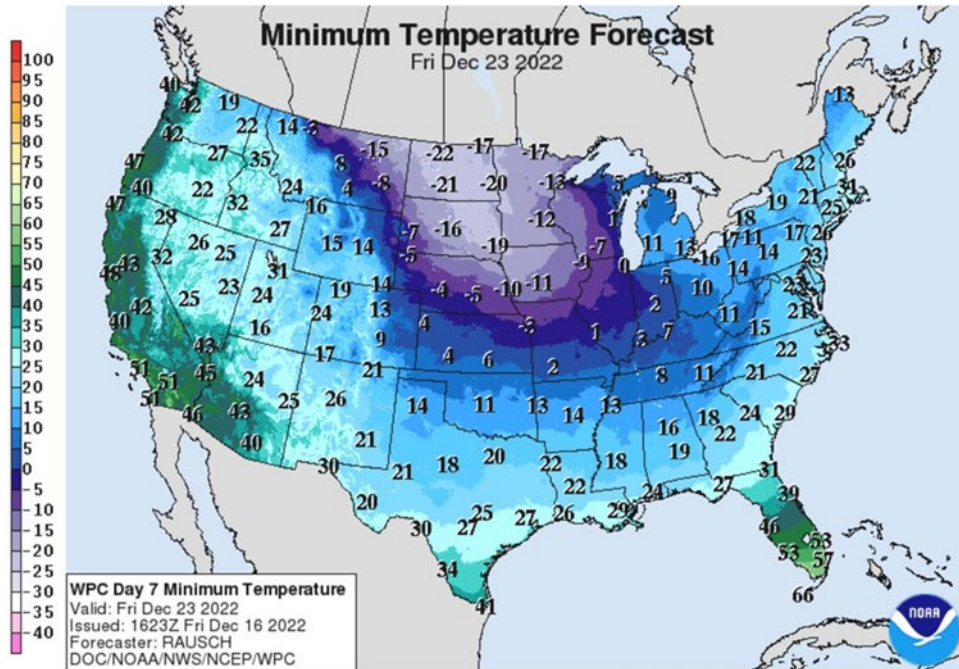
Top 10 Winter Peak Days: History

Rank	Date	Load MW with Addbacks	Emergency Declared Satisfying PAI in Peak Hour?	Scheduled Net Imports at Peak Hour	Hour Beginning
1	2/20/2015	143,434	No	6994	07:00
2	1/7/2014	142,980	Yes, entire RTO	9432	18:00
3	2/19/2015	140,662	No	5989	19:00
4	1/31/2019	138,109	No	-565	07:00
5	1/24/2014	137,706	Yes, MAAC, Dom, AP	6599	07:00
6	1/28/2014	137,659	No	7104	18:00
7	1/5/2018	137,582	No	350	18:00
8	2/5/2007	137,026	No	n/a	n/a
9	1/30/2014	136,437	Yes, MAAC, Dom	3791	07:00
10	1/8/2015	136,419	No	1610	07:00

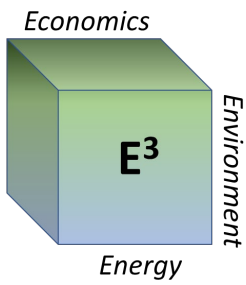
Historically, top winter peaks PJM was a net importer...large net importer.



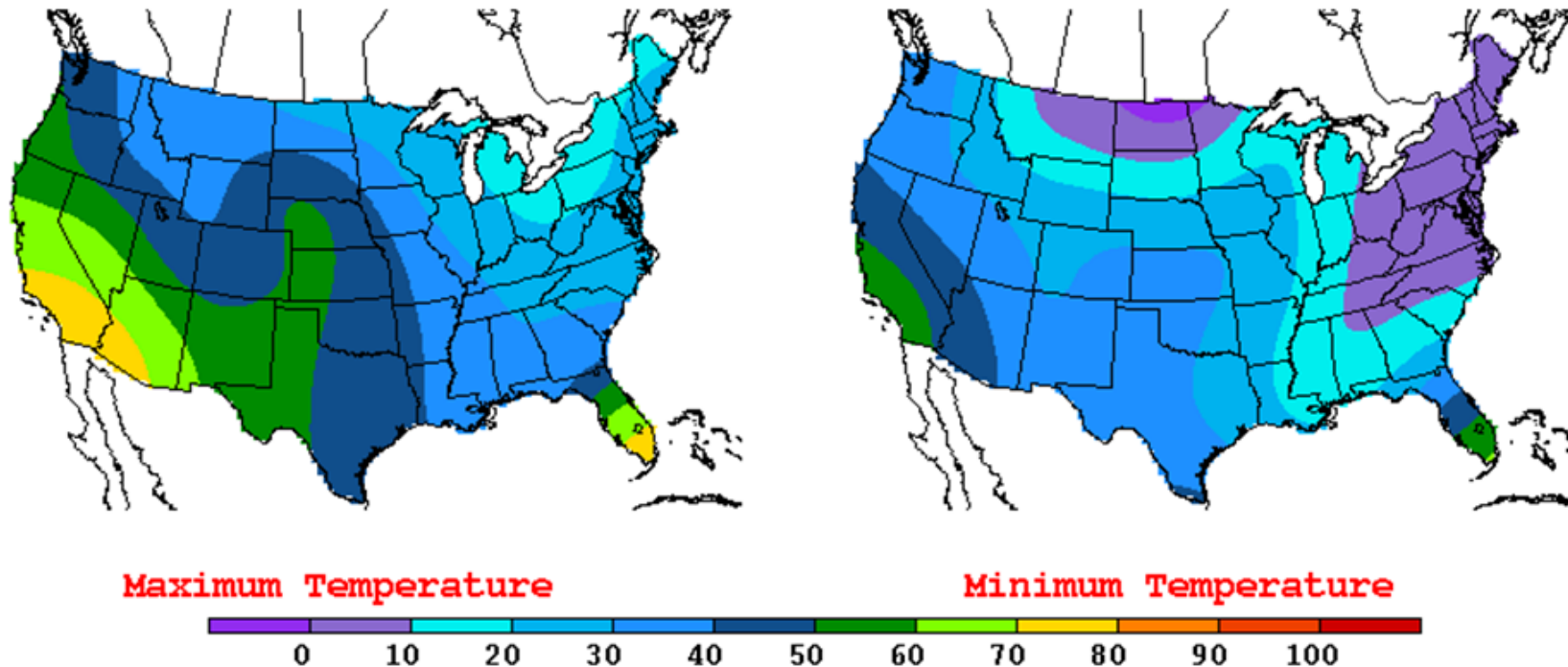
Dec 23-24 Forecast on Dec 16-17...Winter is Coming



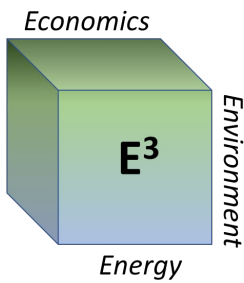
Winter weather was well known in advance



January 30, 2014: #9 Winter Peak Day



Historically, we know temperature like this would lead to much higher loads. Forget about the calendar...look at the weather



Commodity Gas Prices Going into WSE

Gas Trading Point within PJM	Gas Day 12/22 (Traded 12/21 am)	Gas Day 12/23 (Traded 12/22 am)	Gas Day 12/24-12/27 (Traded 12/23 am)
Transco Z6 non-NY	6.27	32.63	28.43
Transco Z5	7.63	59.08	54.56
Tetco M3	6.13	30.95	28.09
TCO	5.03	7.43	6.2
Dom South	4.72	5.17	4.23
Chicago City Gate	17.69	11.8	8.35

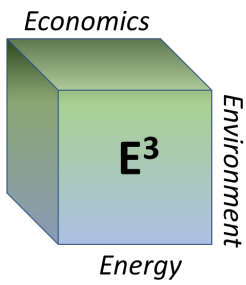
Day-ahead Natural Gas Prices were a strong indication of a strong cold snap in the making in PJM.



Pipeline Operating Conditions

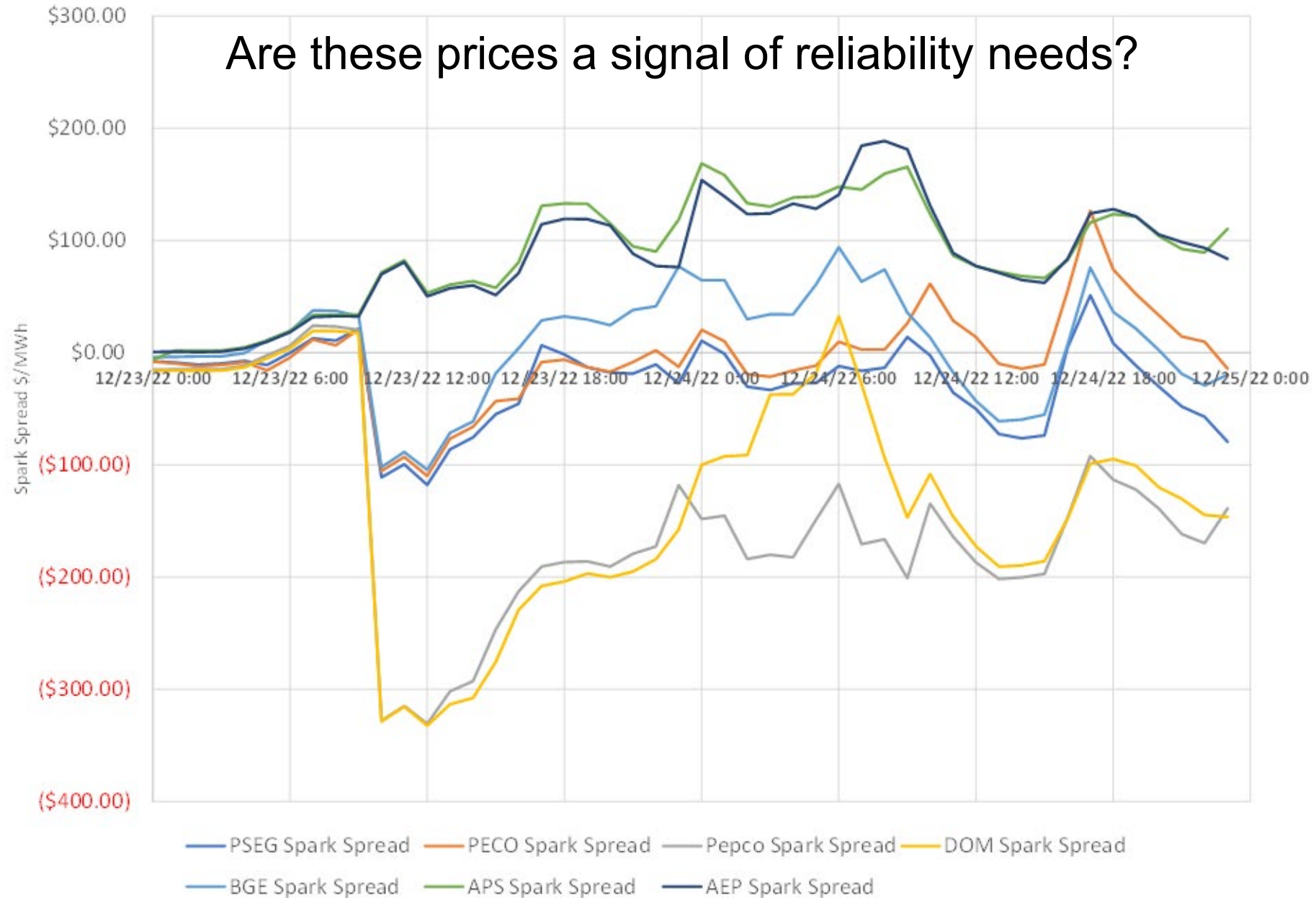
INTERSTATE / INTRASTATE PIPELINE	December																		
	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Adelphia Gateway									4										
ANR		5				6													
BHE EGTS	1																		
	2									7									
BHE Cove Point						2					7								
Columbia Gas Transmission	3																		
			2																
			7																
											8 Force Majeure - Upstream Supply Loss								
Eastern Shore										7									
East Tennessee Natural Gas		7																	
												9							
Horizon							2												
NGPL							2												
				1															
Northern Border											7								
											8 Force Majeure - Upstream Supply Loss								
Panhandle Eastern											7								
Tennessee Gas Pipeline											7								
												9							
Texas Eastern				7						7									
											8 Force Majeure - Loss of multiple compressor stations								
												9							
Texas Gas																			
Transco						7													
											9								
Vector																			

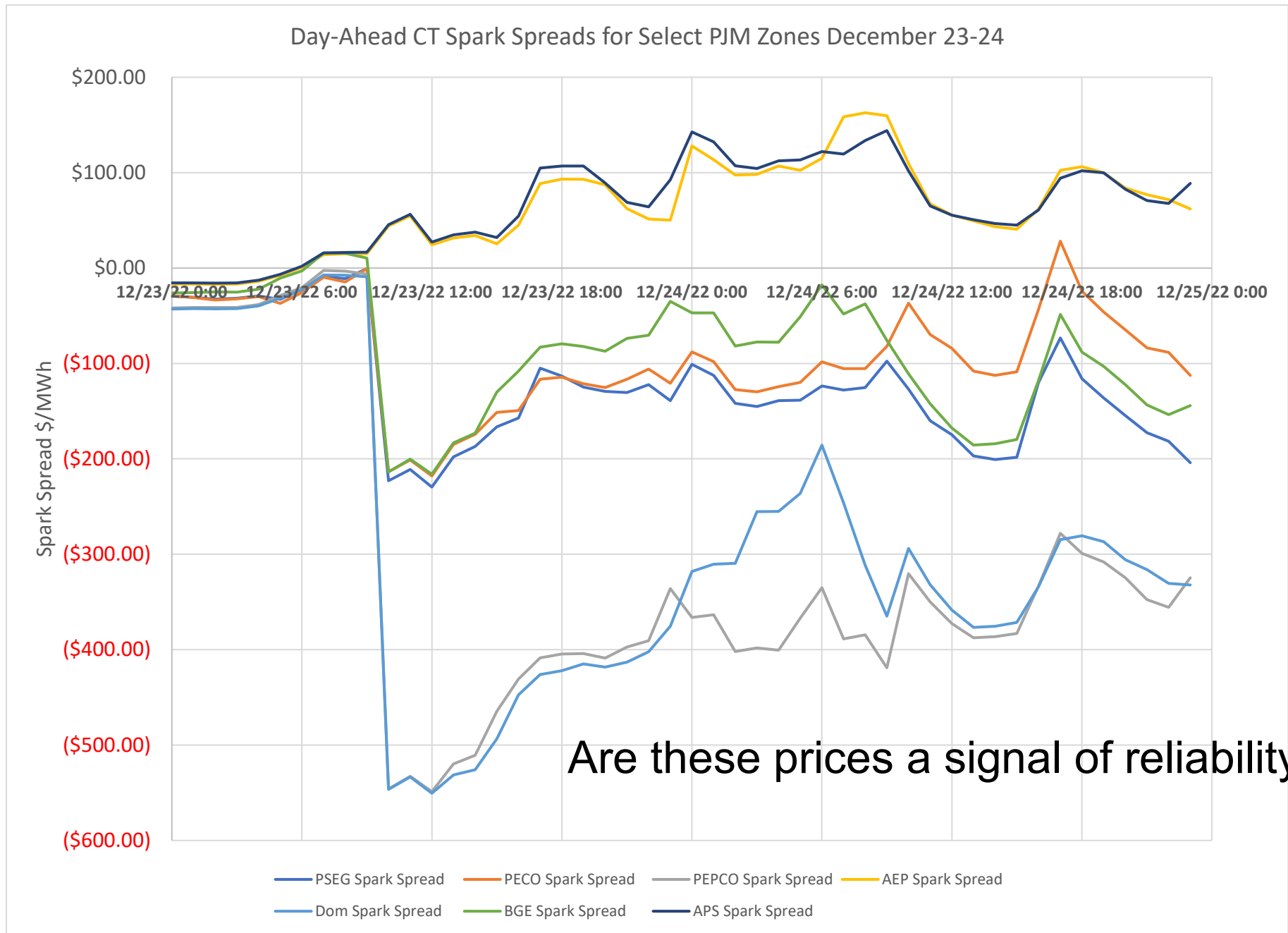
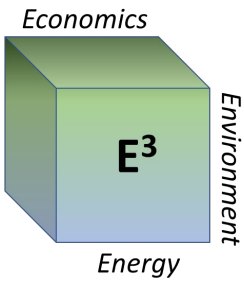
	Pipeline Notice
1	Restrictions on Non-Firm Contracts Customers with interruptible transportation contracts at higher risk of not being able to schedule adequate pipeline capacity
2	Ratable Take Requirement Pipeline requiring customers to supply and burn gas at uniform hourly rates to avoid excessive pressure fluctuations
3	Critical Day (Transport Deliveries/Storage Withdrawals) Pipeline requiring customers to stay within their transportation and storage contractual requirements
4	Action Alert (Daily Balancing) Requires customers to ensure that their supply and demand is balanced at the end of each 24 hour gas day within the tolerances provided by the pipeline tariff provisions
5	Phase 1 Cold Weather Advisory Alerting customers of pending cold temperatures and tightening system conditions
6	Phase 2 Cold Weather Extreme Conditions Requires customers to abide by their specific contract and rate provisions and to burn gas on a uniform hourly basis as their contracts direct. Interruptible contracts at greater risk of having service cut
7	Daily Balancing OFO Requires customers to ensure that their supply and demand is balanced at the end of each 24 hour gas day within the tolerances provided by the pipeline tariff provisions
8	Force Majeure Declared when there is an event outside of the pipeline's control occurs which may render service unavailable to certain customers regardless of contractual arrangements (ex. Loss of compressor station)
9	Loss of Upstream Supply As a result of less gas coming into the pipeline due to upstream supply failures, pipelines provide notice that risk of downstream pressure loss and customer nomination cuts are increasing.



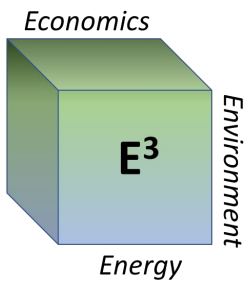
Day-Ahead Combined Cycle Spark Spreads for Select PJM Zones December 23-24

Are these prices a signal of reliability needs?





Are these prices a signal of reliability needs?

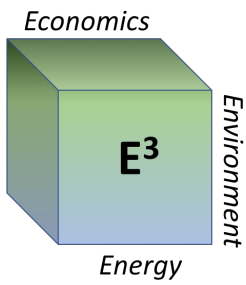


OASIS Confirmed Firm Transmission from PJM

	TVA	Duke	LGE	MISO
Firm Year	525	270	1181	2768
Firm Week (12/19-12/26)	0	0	0	750
Firm Month (12/2022)	500	0	0	750
Firm Day 12/23	876	206	0	1700
Firm Day 12/24	739	1338	0	0

OASIS Confirmed Non-Firm Transmission from PJM

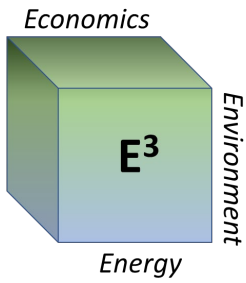
	TVA	Duke	LGE	MISO
Non-Firm Week (12/19-12/26)	50	204	0	0
Non-Firm Month (12/2022)	0	0	0	0
Non-Firm Day 12/23	221	262	0	100
Non-Firm Day 12/24	1544	1044	0	0



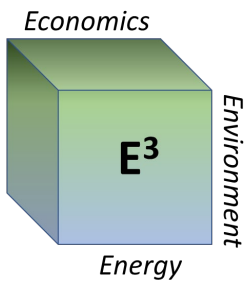
OASIS Confirmed Hourly Non-Firm Transmission from PJM 12/23

Hour Beginning	LGE	Duke	TVA	MISO	Total
12/23/2022 16:00	600	638	2006	1616	5400
12/23/2022 17:00	800	939	2106	1550	6345
12/23/2022 18:00	700	878	2006	1200	5334
12/23/2022 19:00	990	881	2006	1100	5077
12/23/2022 20:00	940	1126	2006	1100	5172
12/23/2022 21:00	940	821	2006	950	4717
12/23/2022 22:00	640	635	2006	750	4031
12/23/2022 23:00	340	641	1506	775	3262

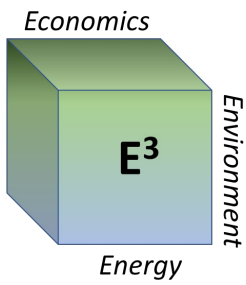
OASIS Confirmed Hourly Non-Firm Transmission from PJM 12/24



Hour Beginning	LGE	Duke	TVA	MISO	Total
12/24/2022 4:00	3	565	1100	500	2408
12/24/2022 5:00	200	1095	1200	500	2995
12/24/2022 6:00	200	845	1160	200	2405
12/24/2022 7:00	250	1047	1991	200	3488
12/24/2022 8:00	250	700	2036	300	3286
12/24/2022 9:00	290	865	2028	300	3483
12/24/2022 10:00	290	768	2043	320	3421
12/24/2022 11:00	290	615	1947	320	3172
12/24/2022 12:00	40	415	1115	320	1890
12/24/2022 13:00	40	515	1115	220	1890
12/24/2022 14:00	40	485	15	220	760
12/24/2022 15:00	40	385	15	220	660
12/24/2022 16:00	40	384	15	220	659
12/24/2022 17:00	40	409	15	220	684
12/24/2022 18:00	40	184	15	220	459
12/24/2022 19:00	40	184	15	220	459
12/24/2022 20:00	40	208	15	220	483
12/24/2022 21:00	40	224	15	220	649
12/24/2022 22:00	40	184	15	220	459



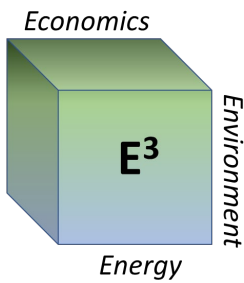
Operating Days 12/23-12/24



Evolution of the December 24 Peak Load Forecast and Forecast Error

Evaluation Time (EPT)	Forecast Hour (EPT)	Load Forecast in MW	Percent Error
12/22/2022 5:45	12/23/2022 18:00	123,499	-9.32%
12/22/2022 9:45	12/23/2022 18:00	124,439	-8.63%
12/22/2022 11:45	12/23/2022 18:00	125,821	-7.62%
12/22/2022 17:45	12/23/2022 18:00	125,821	-7.62%
12/22/2022 23:45	12/23/2022 18:00	125,821	-7.62%
12/23/2022 5:45	12/23/2022 18:00	125,475	-7.87%
12/23/2022 9:45	12/23/2022 18:00	125,475	-7.87%
12/23/2022 11:45	12/23/2022 18:00	125,475	-7.87%
12/23/2022 17:45	12/23/2022 18:00	130,409	-4.25%

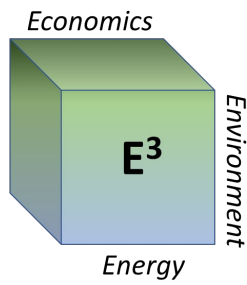
Evaluation Time (EPT)	Forecast Hour (EPT)	Load Forecast in MW	Percent Error
12/23/2022 5:45	12/24/2022 8:00	119,745	-8.62%
12/23/2022 9:45	12/24/2022 8:00	119,798	-8.58%
12/23/2022 11:45	12/24/2022 8:00	119,837	-8.55%
12/23/2022 17:45	12/24/2022 8:00	120,177	-8.29%
12/23/2022 23:45	12/24/2022 8:00	126,155	-3.73%
12/24/2022 5:45	12/24/2022 8:00	129,244	-1.37%



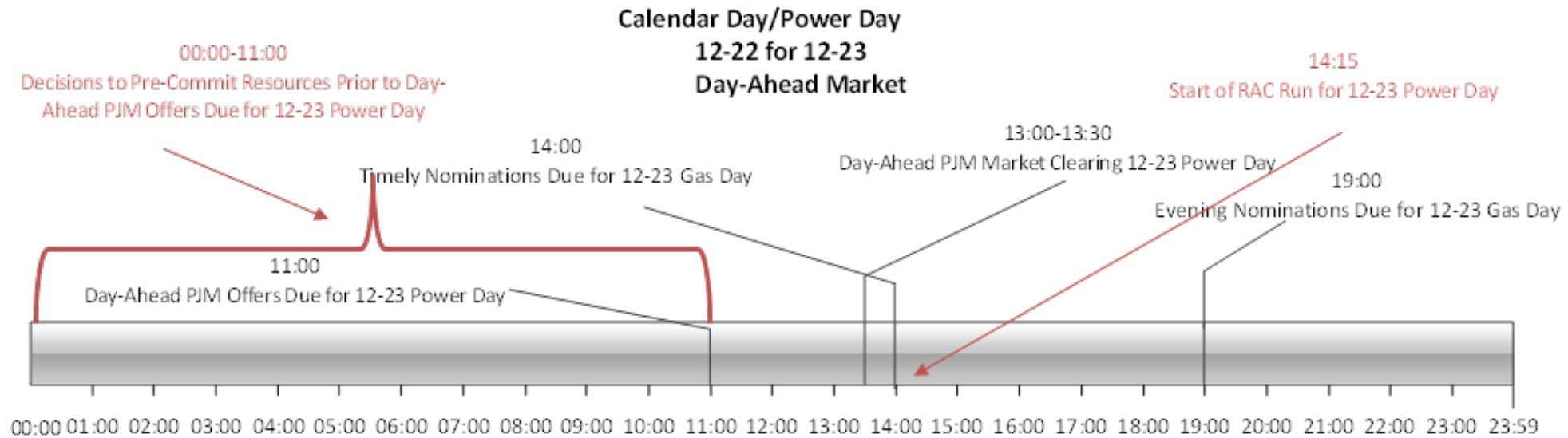
PJM Top 10 Winter Peak Load Days vs. Elliott Peak Loads

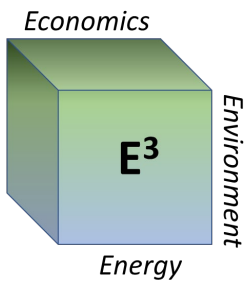
Rank	Date	Load MW	Coincident Load MW	DR MW	Final MW
1	2/20/2015	143,129	96	209	143,434
2	1/7/2014	140,510	118	2,352	142,980
3	2/19/2015	140,386	102	175	140,662
4	1/31/2019	138,060	-	49	138,109
5	1/24/2014	136,982	123	601	137,706
6	1/28/2014	137,336	127	196	137,659
7	1/5/2018	137,465	83	34	137,582
8	2/5/2007	118,800	17,945	281	137,026
9	1/30/2014	136,215	111	111	136,437
10	1/8/2015	136,197	117	106	136,419
	12/23/2022	134,699	---	1500	136,199
	12/24/2022	128,541	---	2500	131,041

WSE was not even a Top 10 Winter Peak Load Day



Timeline of DA Market Clearing, RAC Run, and Gas Nominations



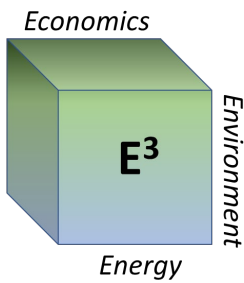


Date, Time	Zone	Max MW Committed
12/23/2022 7:32	DOM	80
12/23/2022 10:21	PECO	17
12/23/2022 10:21	PECO	17
12/23/2022 10:22	PECO	17
12/23/2022 10:22	PECO	17
12/23/2022 10:23	PECO	17
12/23/2022 10:24	PSEG	43.8
12/23/2022 10:25	PSEG	42
12/23/2022 10:25	PSEG	42
12/23/2022 10:25	PSEG	42
12/23/2022 10:26	PSEG	46.9
12/23/2022 10:26	PSEG	46.9
12/23/2022 10:27	PSEG	43.7
12/23/2022 10:35	PSEG	42
12/23/2022 11:10	PEPCO	54
12/23/2022 11:41	DOM	90
12/23/2022 12:47	COMED	175
12/23/2022 12:50	JCPL	182
12/23/2022 13:10	COMED	175
12/23/2022 13:49	PPL	44
12/23/2022 14:13	PSEG	80.2
12/23/2022 14:44	JCPL	150
12/23/2022 14:53	DAY	13.8
12/23/2022 15:04	DAY	13.3
12/23/2022 15:27	AECO	55
12/23/2022 15:33	AECO	41
12/23/2022 16:29	PECO	13
12/23/2022 16:29	PECO	13
12/23/2022 16:31	PECO	13

Capacity Related
Commitments:

No commitments made
For 12/23 on 12/22

Why such small
commitments?



Date, Time	Zone	Max MW Committed
12/23/2022 7:12	BGE	635
12/23/2022 7:13	BGE	638
12/23/2022 7:22	DEOK	82
12/23/2022 7:35	DEOK	82
12/23/2022 7:59	BGE	109.8
12/23/2022 8:53	DEOK	85
12/23/2022 12:32	DOM	425
12/23/2022 12:32	DOM	437.1
12/23/2022 18:30	PECO	568

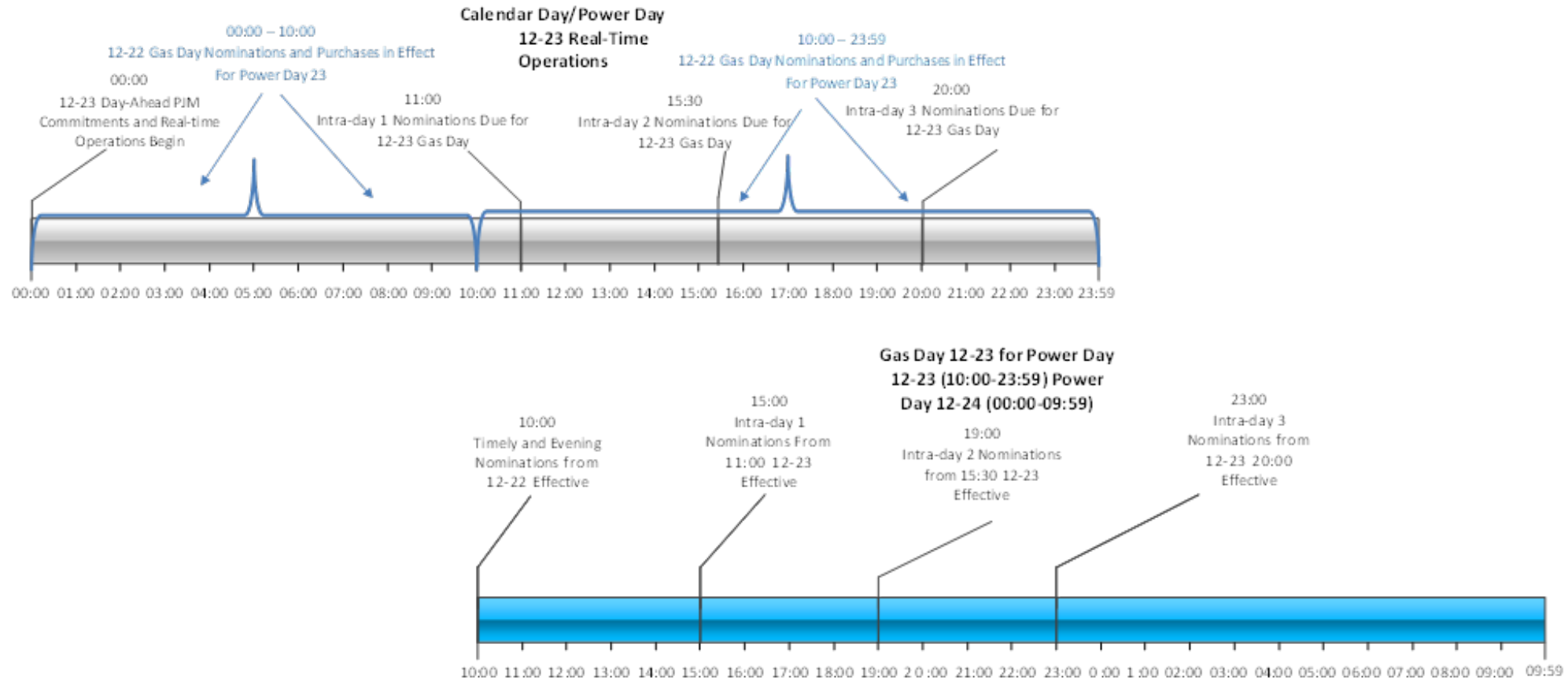
Constraint Management
Commitments:

No commitments made
For 12/23 on 12/22

What were lead times?

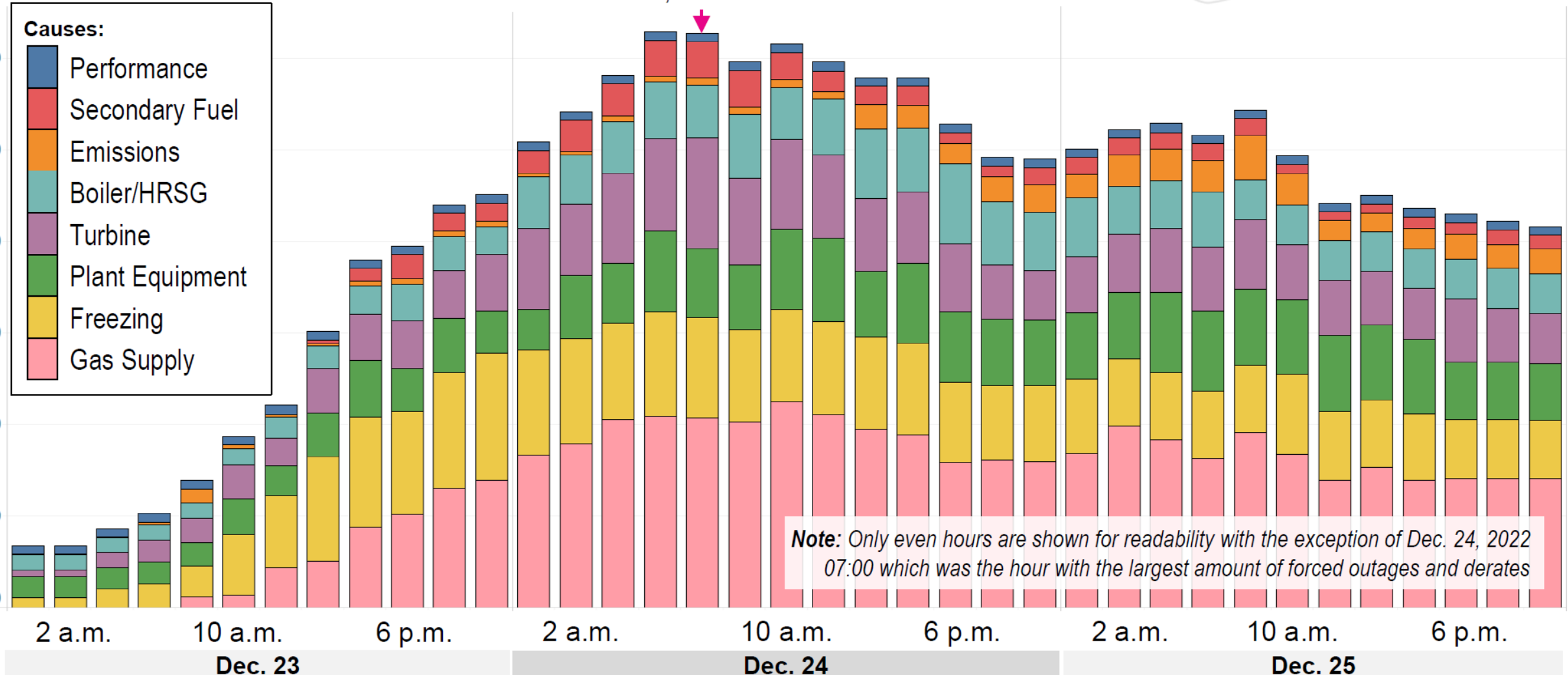
Appears more
concerned with
congestion than load

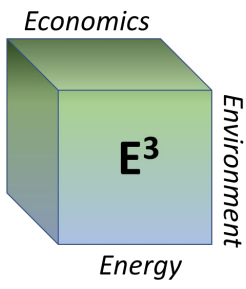
Overlap of PJM Operating Day with the Intra-day Gas Nomination and Flow Cycles



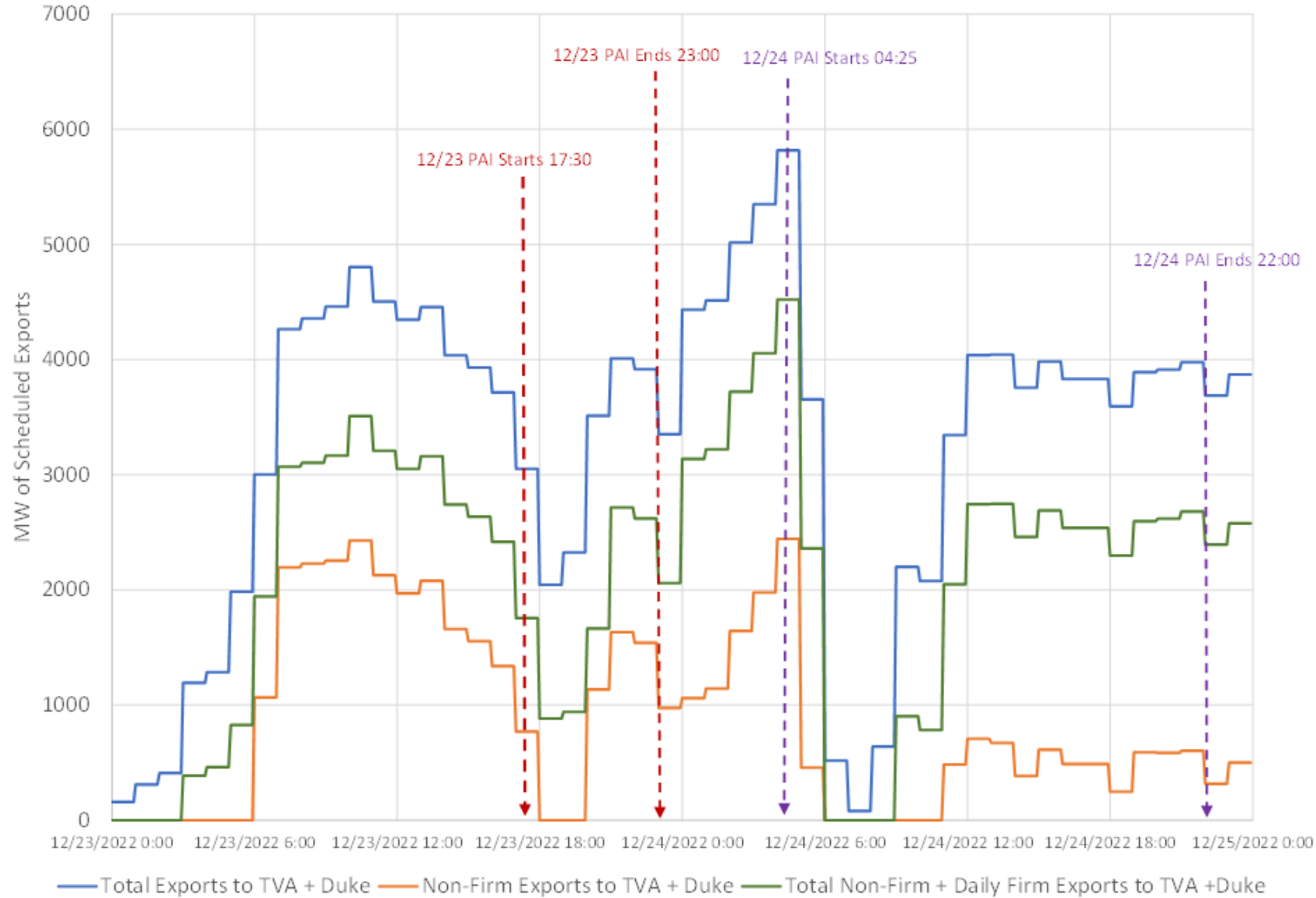
Gas – Forced Outages/Derates by Cause

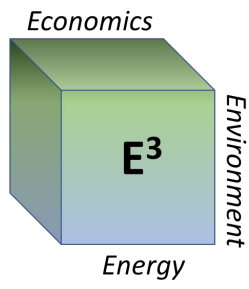
SATURDAY, DEC. 24 AT 07:00



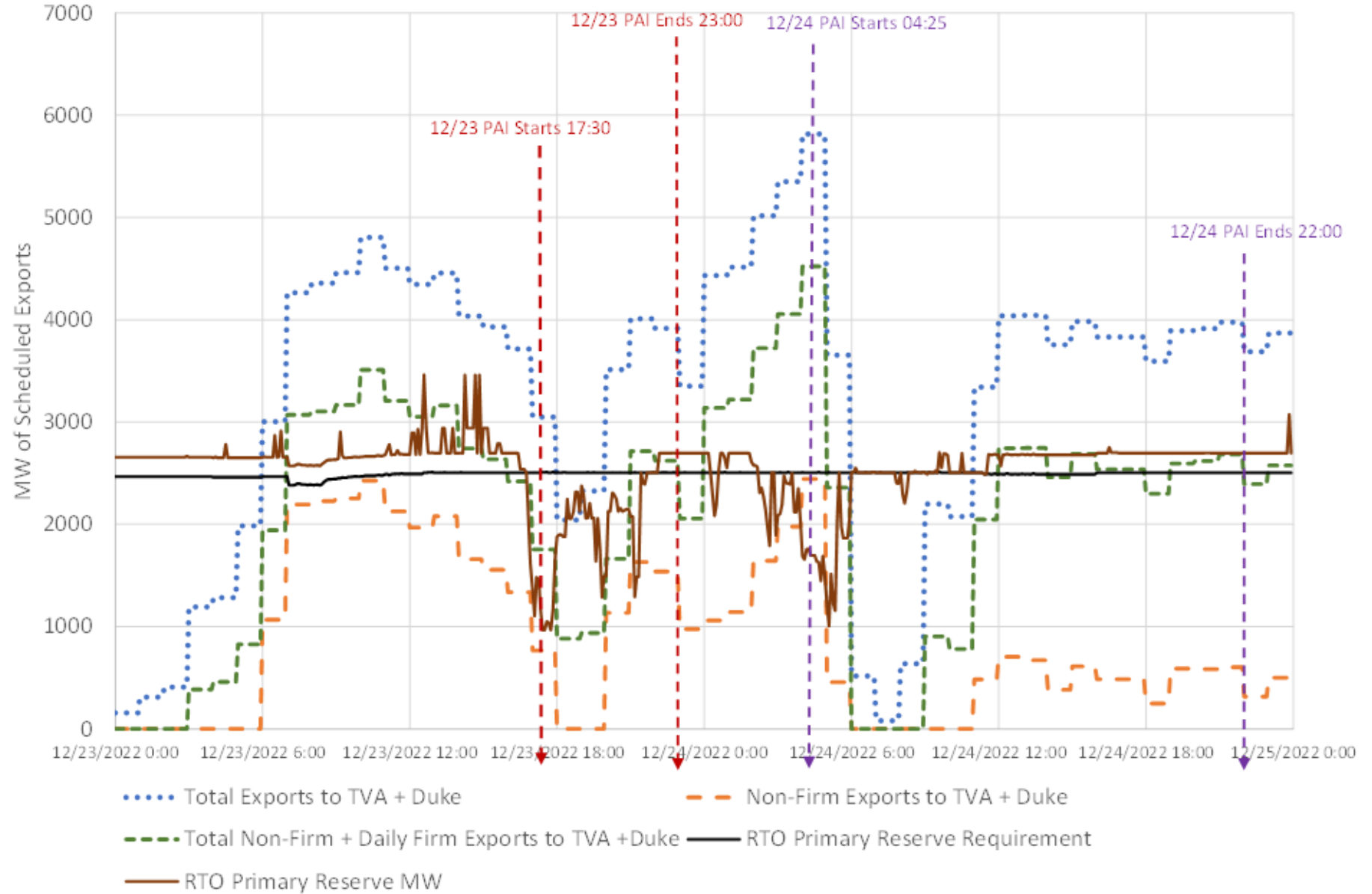


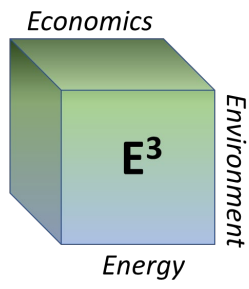
Total, Non-Firm, and Non-Firm + Daily Firm Exports to TVA and Duke December 23-24



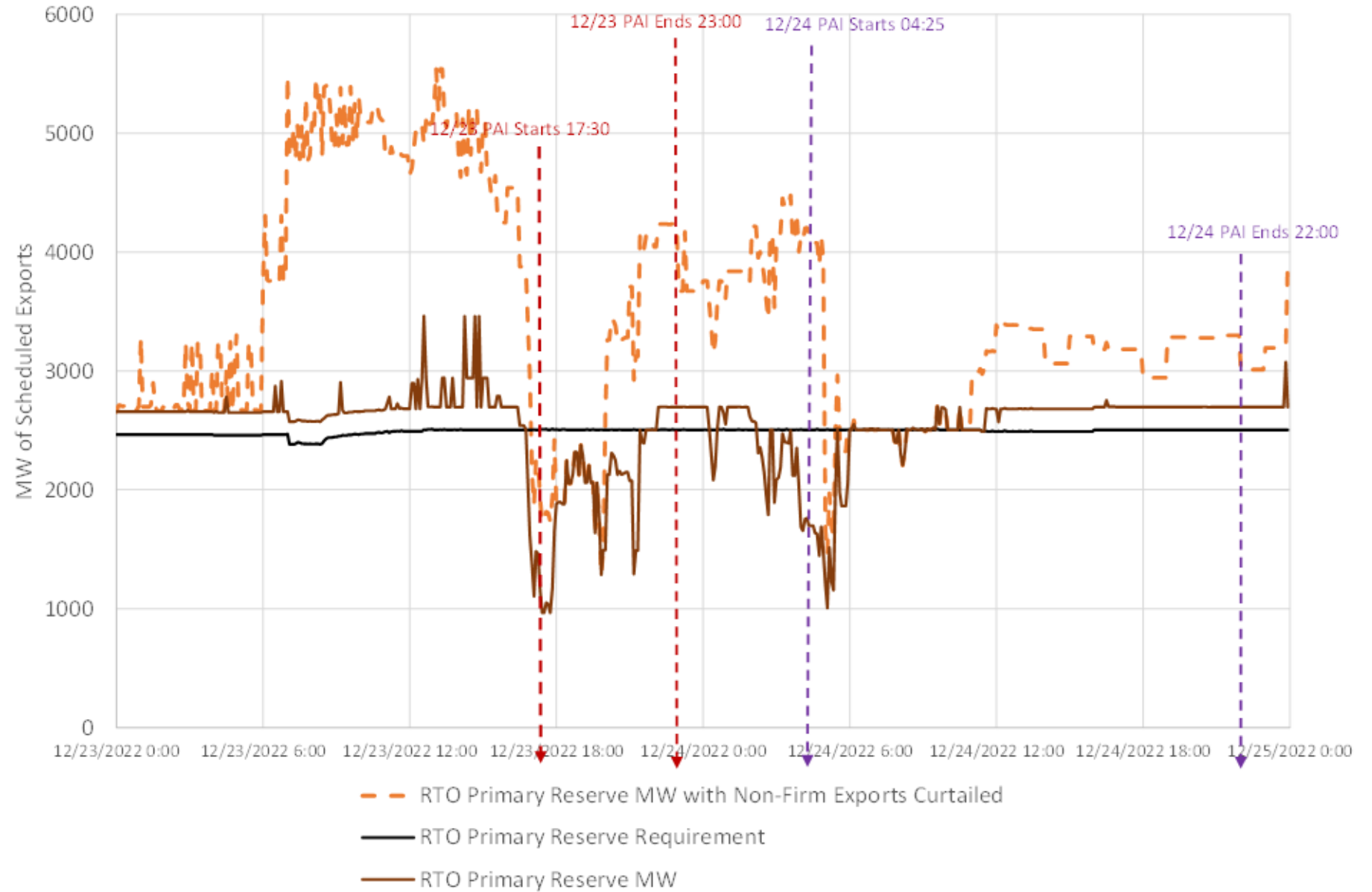


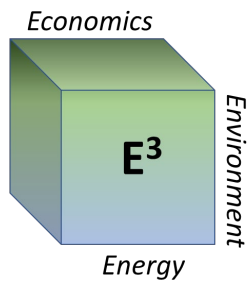
RTO Primary Reserve MW and Requirement with Total, Non-Firm, and Non-Firm + Daily Firm Exports to TVA and Duke December 23-24



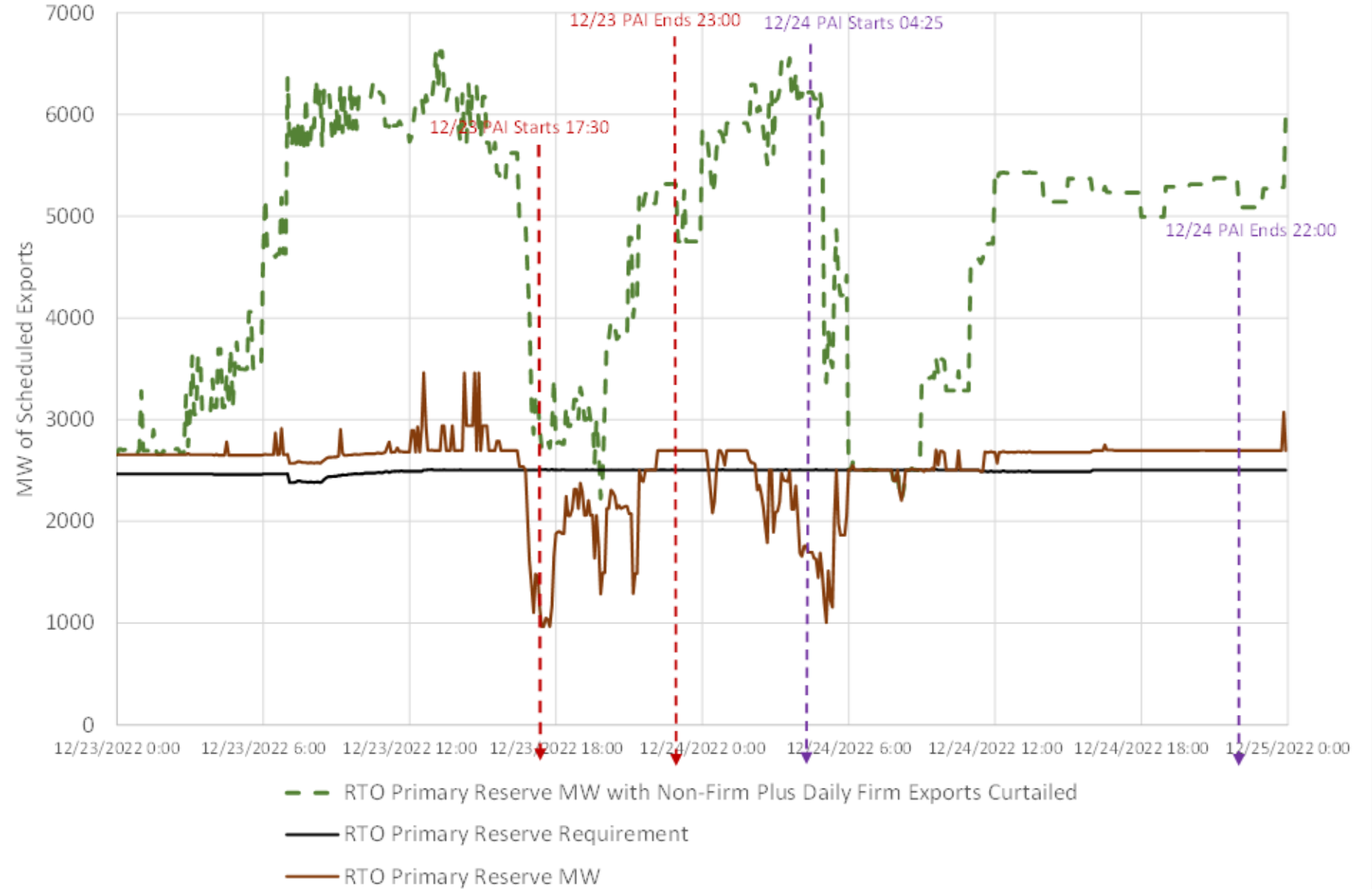


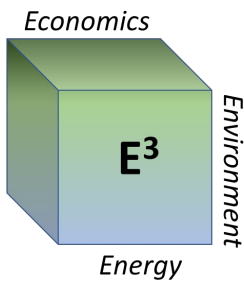
RTO Primary Reserve MW , Requirement, and Primary Reserve MW with Non-Firm Exports to TVA and Duke Curtailed December 23-24





RTO Primary Reserve MW , Requirement, and Primary Reserve MW with Non-Firm + Daily Firm Exports to TVA and Duke Curtailed December 23-24





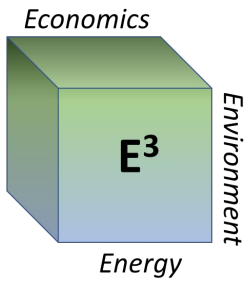
LDA NAME	Cost at PAI all 277 Intervals at Penalty Charge Rate based on Net CONE(\$/MW)	Years of Capacity Revenue lost at 277 PAI at Current Net CONE Penalty Charge Rate (\$/MW)	Cost at Penalty Charge Rate based on BRA Price in all 277 Intervals (\$/MW)	Years of Capacity Revenue lost at 277 PAI at BRA based Penalty Charge Rate (\$/MW)
ATSI	\$61,446.56	3.45	\$14,042.36	0.77
ATSI- CLEVELAND	\$61,446.56	3.45	\$14,042.36	0.77
BGE	\$60,345.64	1.34	\$35,527.17	0.77
COMED	\$66,074.93	2.69	\$19,367.22	0.77
DAY	\$60,331.60	3.39	\$14,042.36	0.77
DEOK	\$59,615.44	2.34	\$20,133.94	0.77
DPL-SOUTH	\$62,960.33	1.81	\$27,483.71	0.77
EMAAC	\$69,138.97	1.98	\$27,483.71	0.77
MAAC	\$65,344.72	1.92	\$26,902.36	0.77
PEPCO	\$69,183.90	2.03	\$26,902.36	0.77
PPL	\$66,754.58	1.96	\$26,902.36	0.77
PS-NORTH	\$71,559.87	2.05	\$27,483.71	0.77
PSEG	\$71,559.87	2.05	\$27,483.71	0.77
RTO	\$69,442.28	3.90	\$14,042.36	0.77
SWMAAC	\$64,766.18	1.90	\$26,902.36	0.77

^[1] (Penalty Charge Rate at Net CONE) x 277. This is for a single MW of a Capacity Resource that did not deliver any energy in any of the 277 declared PAI Intervals on December 23-24.

^[2] (Penalty Charge Rate at Net CONE) x 277 intervals) / (BRA price x 365 days).

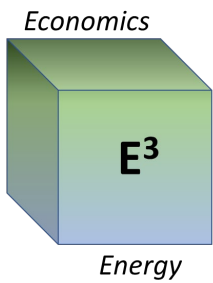
^[3] (Penalty Charge Rate at BRA price) x 277. This is for a single MW of a Capacity Resource that did not deliver any energy in any of the 277 declared PAI Intervals on December 23-24.

^[4] (Penalty Charge Rate at BRA price) x 277 intervals) / (BRA price x 365 days).



Reliability and Markets: Making Sense of Non-Sense

- During and prior to WSE, call on Demand Response, which is a Capacity Resource, required triggering Emergency Actions and a PAI.
- It makes no sense to trigger Emergency Actions to reach for Capacity Resources
- Why is the penalty tied to the Net CONE? This is not the market price or replacement price for capacity.
- Members approved a change to move triggers to include Emergency Actions beyond Demand response plus at least a Primary Reserve Shortage to be a PAI Trigger, and tie penalties to BRA price.



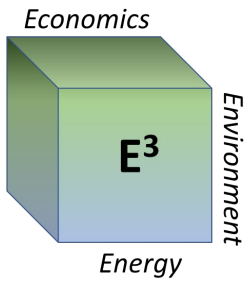
LDA NAME	Cost at PAI all 73 Intervals at Penalty Charge Rate based on Net CONE(\$/MW)	Years of Capacity Revenue lost at 73 PAI at Current Net CONE Penalty Charge Rate (\$/MW)	Cost at Penalty Charge Rate based on BRA Price in all 73 Intervals (\$/MW)	Years of Capacity Revenue lost at 73 PAI at BRA based Penalty Charge Rate (\$/MW)
ATSI	\$16,193.50	0.89	\$3,700.69	0.20
ATSI-CLEVELAND	\$16,193.50	0.89	\$3,700.69	0.20
BGE	\$15,903.36	0.34	\$9,362.76	0.20
COMED	\$17,413.25	0.69	\$5,104.00	0.20
DAY	\$15,899.66	0.87	\$3,700.69	0.20
DEOK	\$15,710.93	0.60	\$5,306.06	0.20
DPL-SOUTH	\$16,592.43	0.46	\$7,243.00	0.20
EMAAC	\$18,220.74	0.51	\$7,243.00	0.20
MAAC	\$17,220.81	0.49	\$7,089.79	0.20
PEPCO	\$18,232.58	0.52	\$7,089.79	0.20
PPL	\$17,592.36	0.50	\$7,089.79	0.20
PS-NORTH	\$18,858.74	0.53	\$7,243.00	0.20
PSEG	\$18,858.74	0.53	\$7,243.00	0.20
RTO	\$18,300.67	1.00	\$3,700.69	0.20
SWMAAC	\$17,068.34	0.49	\$7,089.79	0.20

^[1] (Penalty Charge Rate at Net CONE) x 73. This is for a single MW of a Capacity Resource that did not deliver any energy in any of the 73 declared PAI Intervals that were concurrent with a reserve shortage on December 23-24.

^[2] (Penalty Charge Rate at Net CONE) x 73 intervals) / (BRA price x 365 days).

^[3] (Penalty Charge Rate at BRA price) x 73. This is for a single MW of a Capacity Resource that did not deliver any energy in any of the 73 declared PAI Intervals that were concurrent with a reserve shortage on December 23-24.

^[4] (Penalty Charge Rate at BRA price) x 73 intervals) / (BRA price x 365 days).



Moving Forward from WSE

- Failure to match up weather with history leads to huge forecast error
 - Failure to see how other markets and participants are reacting
 - Failure to commit enough additional units until too late
 - Failure of gas-electric coordination and operator understanding of gas pipeline rules and needs to maintain reliability
 - Imposing default operating parameters on generation that are not physically feasible in the name of market power mitigation
 - Penalties that are multiples of market price that will drive out needed resources
 - Seeming fixture of PJM to not incur uplift
 - Continued non-firm and daily firm exports even during reserve shortages
 - Generator Outages ...how many lack of fuel was really about gas-electric coordination? Most if not all.
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- As an industry we cannot continue to make these mistakes, or it will kill the energy transition because reliability will not be maintained.