Sustainable Capacity Market (SCM)

June 28, 2023

CIFP Stage 3

IMM

Monitoring Analytics

SCM: Key Elements

1. Capacity offered in the forward capacity market, ACAP (available capacity), is (ICAP * MEAF), where MEAF is the modified equivalent availability factor.
2. Capacity is paid in the delivery year only when available to produce energy, by hour. (Hourly price = annual capacity market clearing price/8,760)
3. Capacity market prices are single annual clearing prices by constrained LDAs determined per existing market rules defining LDA constraints.

SCM: Key Elements

4. Must offer requirement in the capacity market applies to all existing capacity resources.
5. Must offer requirement in the energy market means that all committed capacity resources must offer all capacity at ICAP MW in a combination of the energy, ancillary services and reserve markets.
6. Capacity resources that require fuel must have firm fuel in the form of dual fuel capability with a defined number of days of onsite stored fuel, or multiple pipelines with firm transportation and a firm commodity supply.

SCM: Key Elements

7. **Capacity resources must be subject to weekly testing on a schedule determined by PJM that would include the results of economic operations.**

SCM Basics

- **The SCM proposed changes to the capacity market design are simple.**
- **The capacity market clearing process accounts for the expected hourly, locational availability of individual resources.**
- **In the delivery year, capacity resources are paid only when they are available.**

SCM Basics

- **In the forward looking capacity market clearing process that defines the resources needed to provide the target level of energy reliability, it is essential to have resource specific, locational hourly availability in order to match resource availability with the reliability objective.**
- **A simple assumption of average annual availability, or the assumption of an equivalent perfect resource at a derated MW value, will not accurately reflect actual expected availability.**

SCM Basics

- **In the delivery year, it is essential to pay for capacity only when it is available to produce energy.**
- **The proposed design matches payment with availability to produce energy and ensures the opportunity for all resource types to cover their net avoidable costs if their actual availability matches their expected availability.**
- **The result is to provide a long term, stable incentive for investment in maintenance and investment in new, reliable resources.**

Hourly Demand

- **PJM reliability analysis is the basis for hourly demand**
- **Hourly demand is a function of approved metric for reliability threshold (LOLE, EUE or LOLH)**

Modified Availability Factor

- **Modified Equivalent Availability Factor (MEAF) for the delivery period (DP) is the ratio of the total capacity hours that are available to the total installed capacity hours of the resource during the delivery period.**

$$MEAF = \frac{\sum_{hour} Available\ MW_{hour}}{ICAP * (Number\ of\ hours\ in\ the\ DP)}$$

- **Offer per available MW**

$$Offer\ (\$/MW - Hour) = \frac{Offer\ (\$/DP)}{MEAF * ICAP * (Number\ of\ hours\ in\ the\ DP)}$$

Availability

- Average hourly available capacity (ACAP) equals MEAF*ICAP
- Analog of UCAP used in the current capacity market
- A competitive capacity offer price equals net ACR divided by ACAP
- The capacity revenue payment equals cleared ACAP MW multiplied by the clearing price ($/ACAP MW)

Hourly Availability

- PJM calculates the expected hourly available capacity (HACAP) based on historical data
- PJM reliability study would be used to calculate expected availability
- HACAP of a thermal resource is a function of its planned, maintenance, forced outages, ambient derates, derates for any reason.
- HACAP of an intermittent resource is a function of the hourly distribution of the underlying energy potential (solar radiance, wind speed).
- HACAP of a demand resource is a function of its expected/offered load reduction.

Example 1: Nuclear Resource (MEAF = 100%)

Hour	ICAP	Offer (HACAP)	Capacity Revnue Recovery ($/Hour) (ACAP in the Energy Market Same as Cleared ACAP in the Capacity Market)
Hour 1	100	100	$5,400.00
Hour 2	100	100	$5,400.00
Hour 3	100	100	$5,400.00
Hour 4	100	100	$5,400.00
Hour 5	100	100	$5,400.00
Hour 6	100	100	$5,400.00
Hour 7	100	100	$5,400.00
Hour 8	100	100	$5,400.00
Hour 9	100	100	$5,400.00
Hour 10	100	100	$5,400.00
Total		1000	$54,000.00

- **Number of Hours in the DP: 10**
- **Offer ($/DP): $54,000.00**
- **MEAF (Percentage): 100.0%**
- **Offer ($/MW-Hour): $\frac{\$54,000}{1*100*10}$ = $54.00**

Example 2: Oil Resource (MEAF = 71.4%)

Hour	ICAP	Offer (HACAP)	Capacity Revnue Recovery ($/Hour) (ACAP in the Energy Market Same as Cleared ACAP in the Capacity Market)
Hour 1	70	52	$5,990.40
Hour 2	70	51	$5,875.20
Hour 3	70	51	$5,875.20
Hour 4	70	50	$5,760.00
Hour 5	70	50	$5,760.00
Hour 6	70	49	$5,644.80
Hour 7	70	51	$5,875.20
Hour 8	70	49	$5,644.80
Hour 9	70	49	$5,644.80
Hour 10	70	48	$5,529.60
Total		500	$57,600.00

- **Number of Hours in the DP: 10**
- **Offer ($/DP): $57,600.00**
- **MEAF (Percentage): 71.4 %**
- **Offer ($/MW-Hour): $\frac{\$57,600}{0.714*70*10}$ = $115.20**

Example 3: Solar Resource (MEAF = 20%)

Hour	ICAP	Offer (HACAP)	Capacity Revnue Recovery ($/Hour) (ACAP in the Energy Market Same as Cleared ACAP in the Capacity Market)
Hour 1	40	0	$0.00
Hour 2	40	0	$0.00
Hour 3	40	5	$450.00
Hour 4	40	10	$900.00
Hour 5	40	25	$2,250.00
Hour 6	40	25	$2,250.00
Hour 7	40	10	$900.00
Hour 8	40	5	$450.00
Hour 9	40	0	$0.00
Hour 10	40	0	$0.00
Total		80	$7,200.00

- **Number of Hours in the DP: 10**
- **Offer ($/DP): 7,200**
- **MEAF (Percentage): 20.0 %**
- **Offer ($/MW-Hour): $\frac{\$7,200}{0.20*40*10}$ = $90.00**

Example 4: Coal Resource (MEAF = 64%)

Hour	Outage	ICAP	Offer (HACAP)	Capacity Revnue Recovery ($/Hour) (ACAP in the Energy Market Same as Cleared ACAP in the Capacity Market)
Hour 1		50	45	$4,556.25
Hour 2	Planned	50	0	$0.00
Hour 3	Planned	50	0	$0.00
Hour 4		50	25	$2,531.25
Hour 5		50	30	$3,037.50
Hour 6		50	35	$3,543.75
Hour 7		50	45	$4,556.25
Hour 8		50	45	$4,556.25
Hour 9		50	45	$4,556.25
Hour 10		50	50	$5,062.50
Total			320	$32,400.00

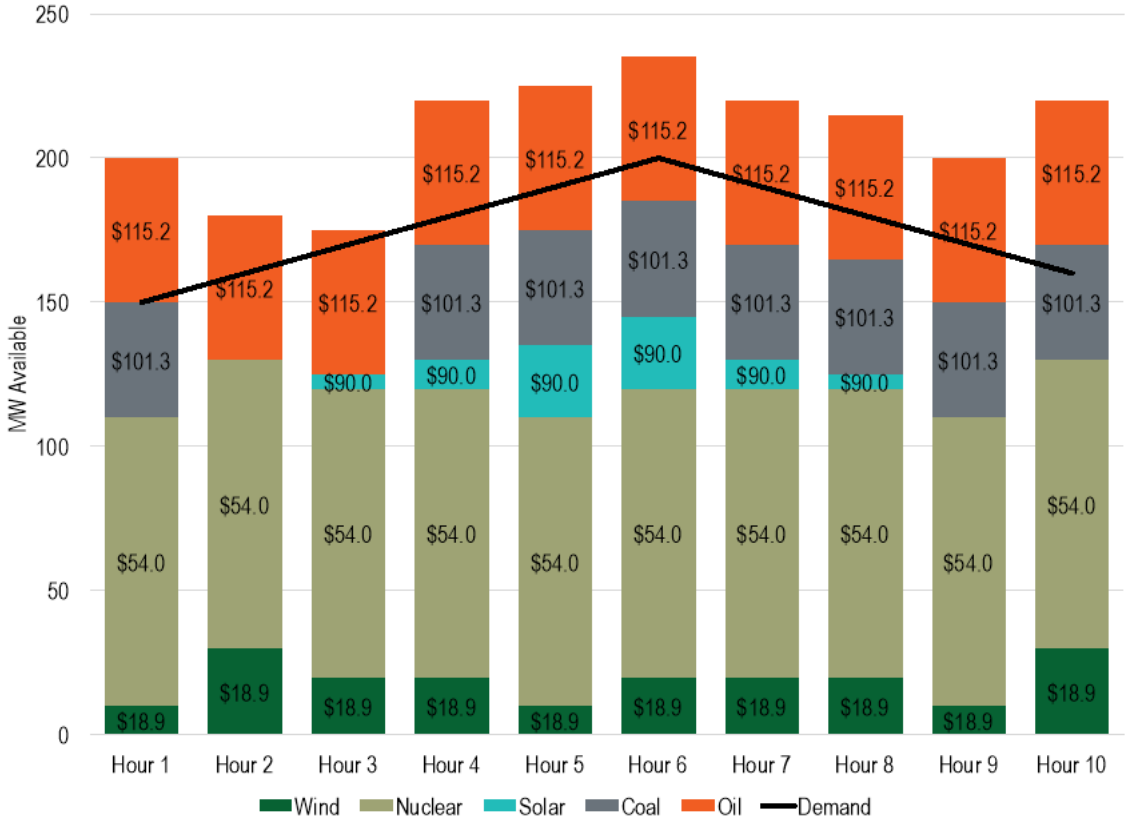
- **Number of Hours in the DP: 10**
- **Offer ($/DP): 32,400.00**
- **MEAF (Percentage): 64 %**
- **Offer ($/MW-Hour):**

$$\frac{\$32{,}400}{0.64 * 50 * 10} = \$101.25$$

Capacity Market Auction Clearing

- Demand is specified as a sequence of hourly reliability requirements
- Objective is to select the least cost set of resources that simultaneously satisfy reliability requirements in all hours in the delivery year
- Clearing price for the delivery year is set by the offer price of the marginal resource

Example: Offers



	Availability (HACAP MW)										ICAP
	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	MW
Nuclear	100	100	100	100	100	100	100	100	100	100	100
Solar	0	0	5	10	25	25	10	5	0	0	40
Wind	10	30	20	20	10	20	20	20	10	30	40
Coal	45	0	0	25	30	35	45	45	45	50	50
Oil	52	51	51	50	50	49	51	49	49	48	70

	ICAP MW	Offer ($/DP)	Offer ($/MW-DP)	MEAF	ACAP MW	Offer ($/MW-Hour)
Nuclear	100.0	$54,000.00	$540.00	1.000	100.0	$54.00
Solar	40.0	$7,200.00	$900.00	0.200	8.0	$90.00
Wind	40.0	$3,600.00	$189.47	0.475	19.0	$18.95
Coal	50.0	$32,400.00	$1,012.50	0.640	32.0	$101.25
Oil	70.0	$57,600.00	$1,152.00	0.714	50.0	$115.20

Number of Hours in the DP: 10

Coal Offer($/DP) = $32,400

Coal Offer($/MW-Hour): $\left(\frac{\$32,400}{0.640 * 50 * 10}\right) = \$101.25$

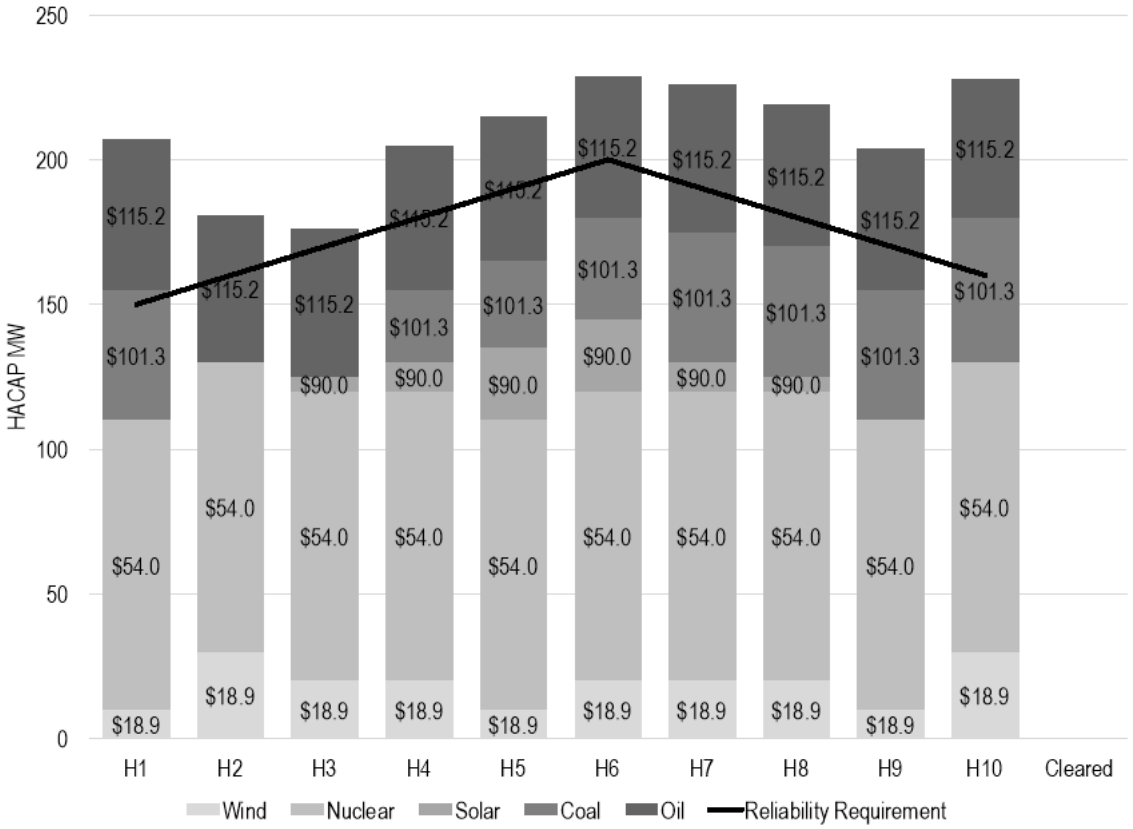
Monitoring Analytics

Example: Capacity Market Auction Clearing

- **The optimization chooses the least cost set of resources that simultaneously satisfy reliability requirements of all hours in the delivery period.**
- **The formulation used for this simple example with a vertical demand curve is provided in the appendix.**
- **A detailed formulation using the downward sloping VRR curve is provided in the IMM memo.**
- **To illustrate the clearing process, the next slides show a step by step selection of resources.[1]**

1. The step by step approach shown here is not the same as how an LP or MIP solver would arrive at the clearing solution.

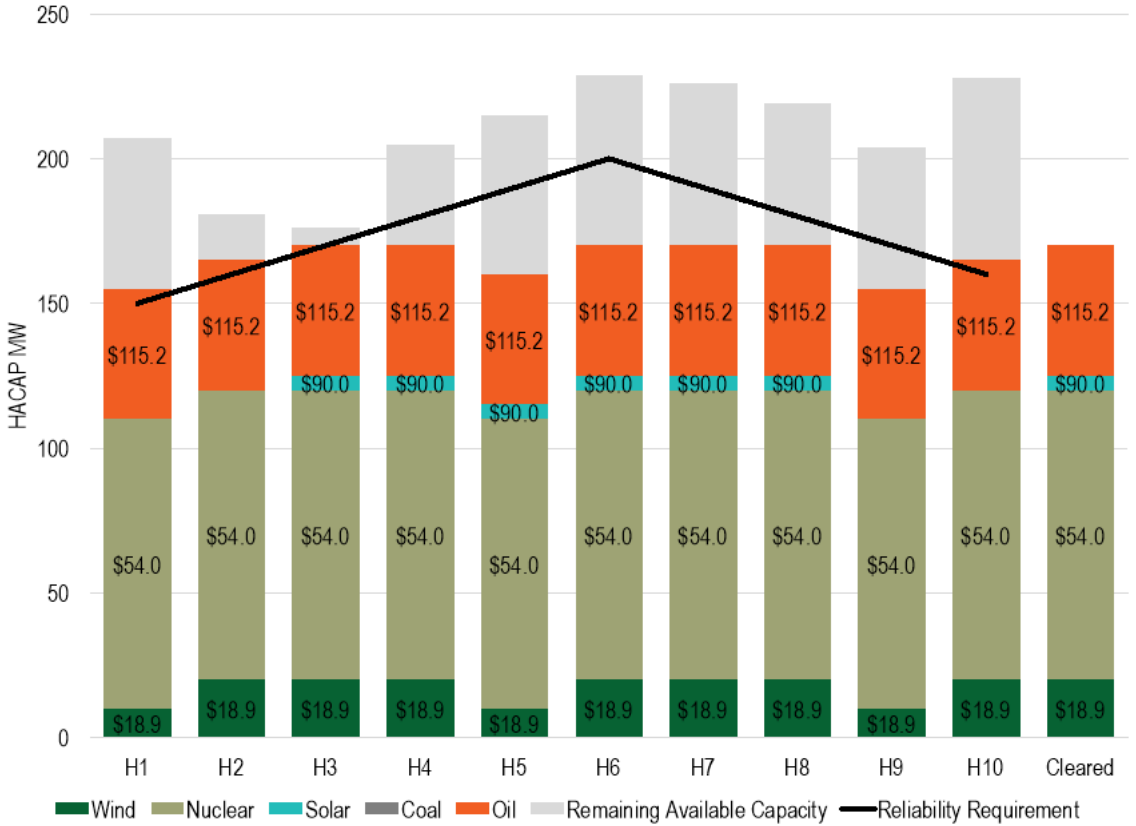
Example: Hourly Availability



- Available Resources by Hour
- Objective is to find a least cost set of resources that satisfies the demand for every hour in the DP

Monitoring Analytics

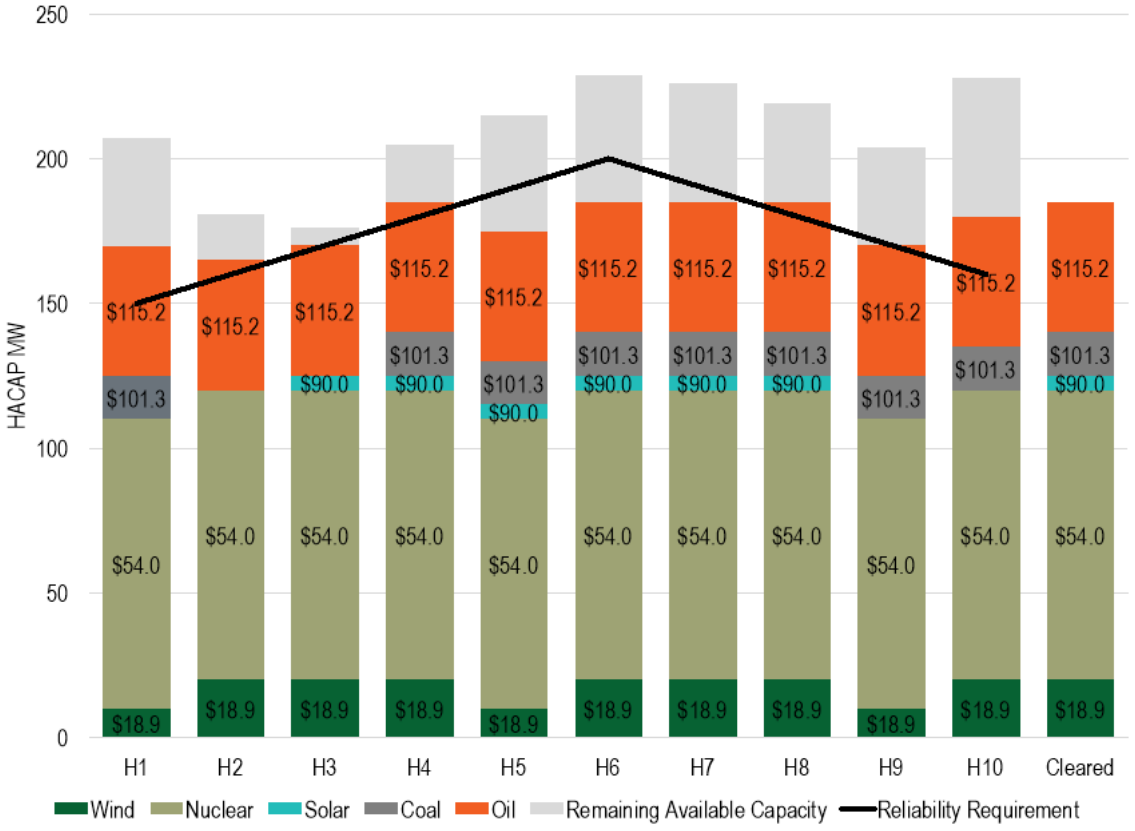
Example: Step 1



- Coal resource is on outage in Hour 3
- 45 HACAP MW of Oil, 100 HACAP MW of Nuclear, 5 HACAP MW of Solar and 20 HACAP MW of Wind satisfies the demand for Hour 3
- Demand for Hour 1 and Hour 10 are also satisfied

Monitoring Analytics

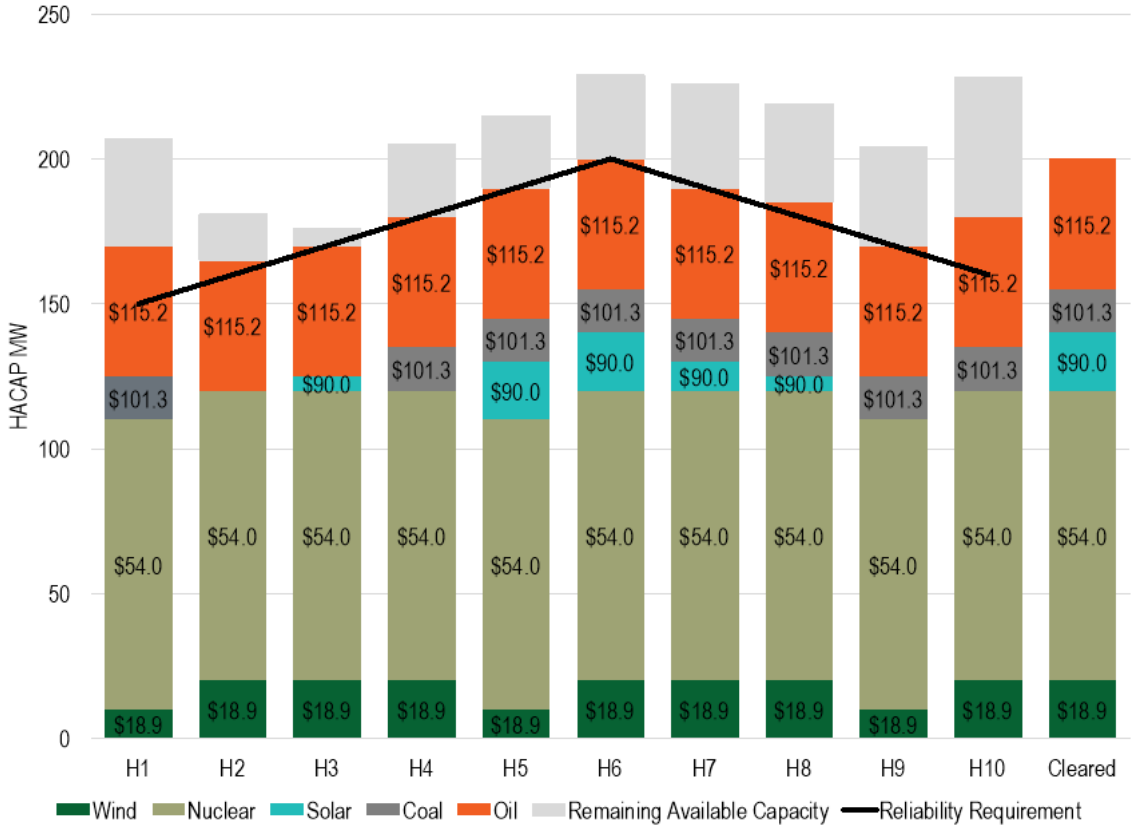
Example: Step 2



- **Clearing additional 15 HACAP MW of Coal satisfies all hours except Hour 5, Hour 6 and Hour 7**

Monitoring Analytics

Example: Solution



- **Increasing the clearing capacity of Solar to 20 HACAP MW satisfies the demand for all hours.**
- **Clearing additional resources does not reduce the overall cost.**

Monitoring Analytics

Example: Auction Results

	ICAP MW	Minimum Hourly Availability (HACAP MW)	Maximum Hourly Availability (HACAP MW)	MEAF	Cleared (HACAP MW)	Cleared (ACAP MW)
Nuclear	100.0	100.0	100.0	1.000	100.0	100.0
Solar	40.0	0.0	25.0	0.200	20.0	6.4
Wind	40.0	10.0	30.0	0.475	20.0	12.7
Coal	50.0	0.0	50.0	0.640	15.0	9.6
Oil	70.0	48.0	52.0	0.714	45.0	43.3

Capacity Revenue Payment

- **If the capacity resource's availability in the energy market matches its offered availability in the capacity market, the resource would recover at least its full offer.**

Example: Capacity Revenue Payment

	Expected Availability used in the Capacity Market Clearing (HACAP MW)										Expected
	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	Availability
Nuclear	100	100	100	100	100	100	100	100	100	100	1.000
Solar	0	0	5	10	25	25	10	5	0	0	0.200
Wind	10	30	20	20	10	20	20	20	10	30	0.475
Coal	45	0	0	25	30	35	45	45	45	50	0.640
Oil	52	51	51	50	50	49	51	49	49	48	0.714

	Availability in the Energy Market (HACAP MW)										Actual
	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	Availability
Nuclear	100	100	100	100	100	100	100	100	100	100	1.000
Solar	0	0	0	5	35	35	5	0	0	0	0.200
Wind	10	30	20	20	10	20	20	20	10	30	0.475
Coal	30	0	20	20	40	50	40	30	50	40	0.640
Oil	70	70	0	70	50	50	50	50	50	40	0.714

	Capacity Revenue ($/Hour)										Total	Factor for Partially
	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	($/DP)	Cleared Resources
Nuclear	$11,520	$11,520	$11,520	$11,520	$11,520	$11,520	$11,520	$11,520	$11,520	$11,520	$115,200	1.00
Solar	$0	$0	$0	$461	$3,226	$3,226	$461	$0	$0	$0	$7,373	0.80
Wind	$768	$2,304	$1,536	$1,536	$768	$1,536	$1,536	$1,536	$768	$2,304	$14,592	0.67
Coal	$1,037	$0	$691	$691	$1,382	$1,728	$1,382	$1,037	$1,728	$1,382	$11,059	0.30
Oil	$6,978	$6,978	$0	$6,978	$4,985	$4,985	$4,985	$4,985	$4,985	$3,988	$49,846	0.87

Clearing Price

- **The clearing price for the delivery year is set by the offer price of the marginal resource for the year.**

Additional Issues Addressed in SCM

- **Must offer in the capacity market**
- **Must offer in the energy market**
- **Market Seller Offer Cap (MSOC)**
- **Issues with ELCC**

Appendix

Formulation

$$Min \sum_{r} CAP_{y,r} * \frac{OFFER_r}{ICAP_r * MEAF_r}$$

Subject to:

$$\forall\, h, \sum_{r} HCAP_{h,r} = RR_h$$

$$\forall\, (r,h), HCAP_{h,r} = AVAIL_{h,r}$$

$$\forall\, (r,h), CAP_{y,r} \geq HCAP_{h,r}$$

Where:

r: capacity resource

h: hour

RR_h: Reliability Requirement (MW) for hour h (parameter)

$OFFER_r$: Offer in $/DY of capacity resource r (parameter)

$CAP_{y,r}$: Maximum cleared capacity (HACAP MW) of resource r for the entire delivery period (variable)

$HCAP_{h,r}$: Cleared capacity (MW) from resource r for hour h (variable)

$AVAIL_{h,r}$: Expected available capacity (HACAP MW) from resource r for hour h (parameter)

Appendix: Capacity Revenue Derivation

Capacity Revenue:

$$\begin{matrix}Capacity\\ Revenue\\ (\$/DP)\end{matrix} = \left(\begin{matrix}Cleared\\ MW\\ (HACAP\ MW)\end{matrix}\right) * \frac{ICAP * MEAF}{Max(Availability_h)} * \left(\begin{matrix}Clearing\\ Price\\ (\$/MW-Hour)\end{matrix}\right) * \left(\begin{matrix}Number\ of\\ hours\ in\ DP\end{matrix}\right)$$

Monitoring Analytics, LLC
2621 Van Buren Avenue
Suite 160
Eagleville, PA
19403
(610) 271-8050

MA@monitoringanalytics.com
www.MonitoringAnalytics.com