ERPIV Informational Presentation

- New real-time reserve market
  - Based on a Real-Time Operating Reserve (RTOR) Requirement
  - Product is actually Real-Time Secondary Reserve (RTSR)
    - Clearing price is the Real-Time Secondary Reserve Clearing Price (RTSRMCP)

<table>
<tr><td colspan="3">Day-Ahead Scheduling Reserve <u>& Real-Time Operating Reserve</u>
(T ≤ 30 Min)</td></tr>
<tr><td colspan="2">Contingency (Primary) Reserve
(T ≤ 10 Min)</td><td rowspan="2">Secondary Reserve
(10 Min ≤ T ≤ 30 Min)</td></tr>
<tr><td>Synchronized Reserve
(Synchronized)</td><td>Non-Synchronized Reserve
(Off-Line)</td></tr>
<tr><td colspan="3">T = Time Interval Following PJM Request</td></tr>
</table>

- Determination of the Penalty Factor, Price Calculation and Price Limits
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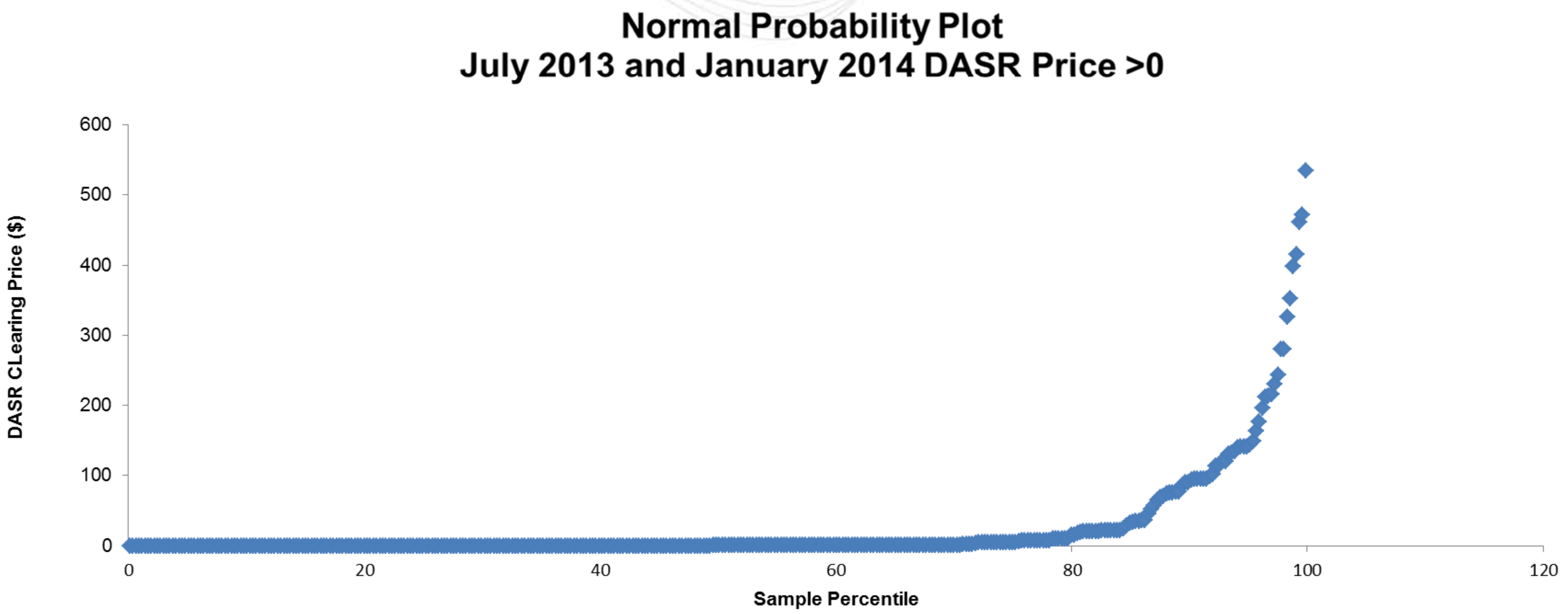
- Lost Opportunity Cost Example
- Market Clearing Examples
- Settlement Examples

- Effective June 01, 2015 the penalty factor for SR and PR will be $850
- Real Time RTO Operating Reserve Penalty Factor by design should be < the penalty factor for SR and PR
- The Real Time RTO Operating Reserve Penalty Factor should be consistent with DASR clearing prices on a peak load day.
- Do not want to base the penalty factor on the most extreme hours observed in January 2014

Analyzed DASR Clearing price data for July 2013 and January 2014 for hours where the clearing price was > 0



- Average DASR Clearing Price = $25.02
- Standard Deviation = $71.34

- Average DASR Clearing Price + 3*Standard Deviation = $239

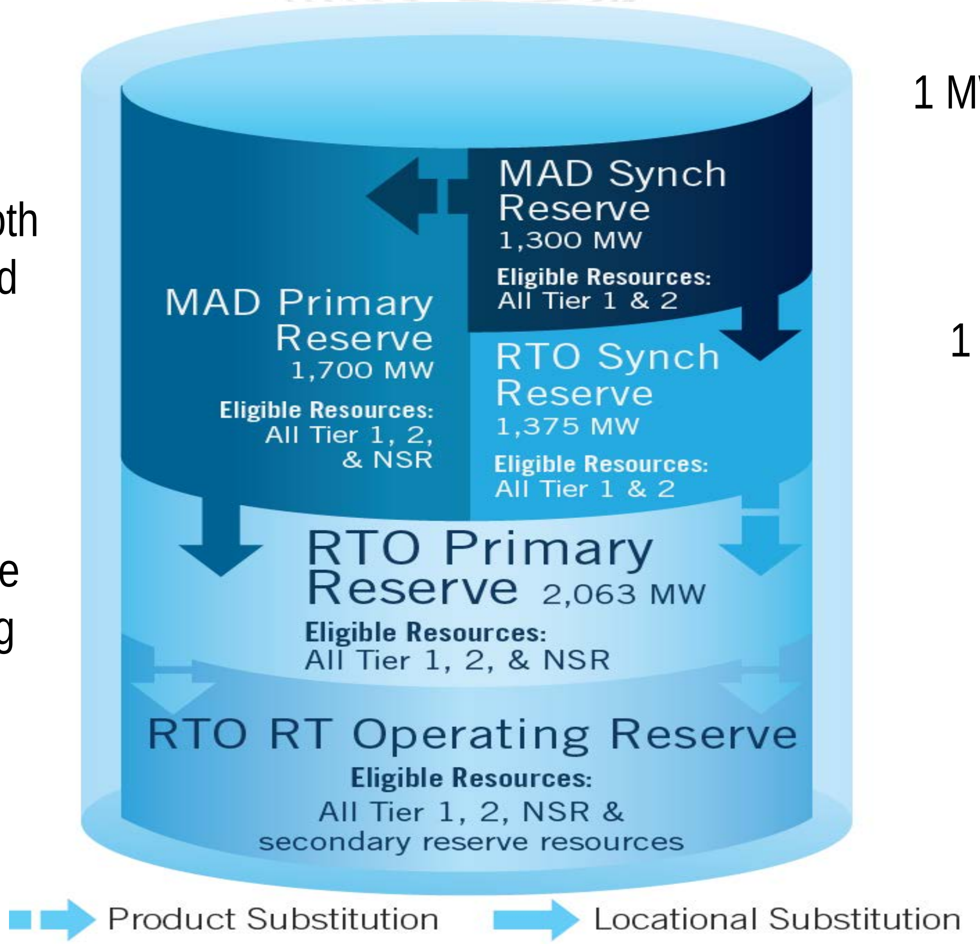
- Add small amount of additional margin sets the Real Time RTO Operating Reserve Penalty Factor = $300

Penalty Factor & Price Limits

Linkage of Reserve Substitution to Reserve Value

1 MW MAD Primary Reserve satisfies both the MAD and RTO Primary Reserve and RTO Operating Reserve requirements

1 MW RTO Primary Reserve satisfies the RTO Primary Reserve and RT Operating Reserve requirements



1 MW MAD Synch Reserve satisfies all 5 requirements

1 MW RTO Synch Reserve satisfies the RTO Synch Reserve, Primary Reserve and RT Operating Reserve requirements

1 MW RTO RT Operating Reserve only satisfies the RTO RT Operating Reserve requirement

Penalty Factor Effect on Max Prices

Synch Reserve / Primary Reserve Penalty Factor	RT Operating Reserve Penalty Factor	Max Energy Price (absent congestion and losses)	Max SRMCP	Max NSRMCP	Max Secondary Reserve Price	Generator Offer Cap
$850	$300	$3000	$2000	$1150	$300	$1,000

Max Energy Price: Gen offer cap + SR penalty factor + PR penalty factor + OR penalty factor

Max SRMCP: SR penalty factor + PR penalty factor + OR penalty factor

Max NSRMCP: PR penalty factor + OR penalty factor

Max Secondary Reserve Price: OR penalty factor

Generator Offer Cap: Unchanged

Pricing During a RT Operating Reserve Shortage

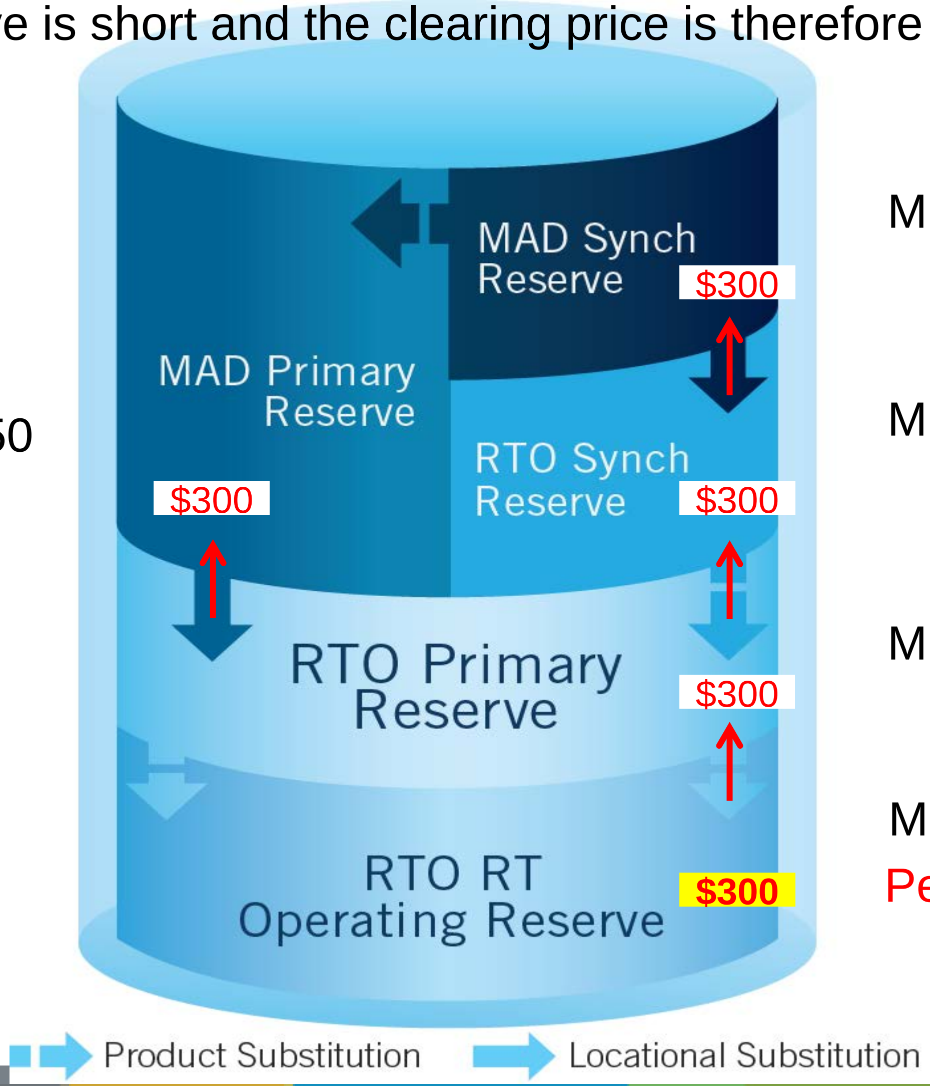
- If short RT Operating Reserve in the RTO reserve zone, the RT Operating Reserve penalty factor is incorporated into the RTO and MAD reserve prices and the LMP

Price	Range
RTO RT Operating Reserve	$300
RTO Non-Synchronized Reserve	$300 - $1150
RTO Synchronized Reserve	$300 - $2000
MAD Non-Synchronized Reserve	$300 - $1150
MAD Synchronized Reserve	$300 - $2000
LMP	Cost to serve the next MW of energy inclusive of RT OR shortage

Impact of RT Operating Reserve Penalty Factor on Other Reserve Clearing Prices

Assume RT Operating Reserve is short and the clearing price is therefore set equal to the penalty factor…

Min: $300 Max: $1150



Min: $300 Max: $2000

Min: $300 Max: $2000

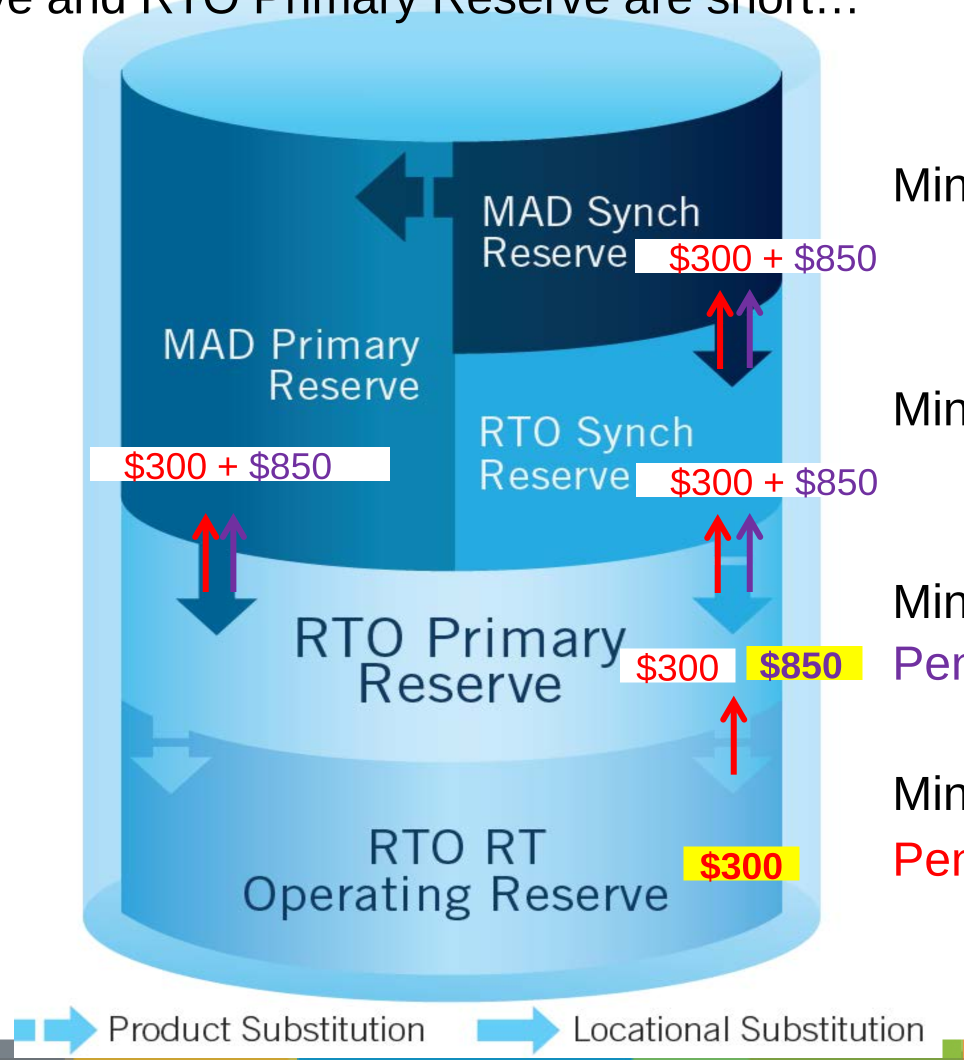
Min: $300 Max: $1150

Min: $300 Max: $300

Penalty Factor = $300

Impact of Multiple Reserve Shortages

Assume RT Operating Reserve and RTO Primary Reserve are short…



Min: $1150 Max: $2000

Min: $1150 Max: $1150

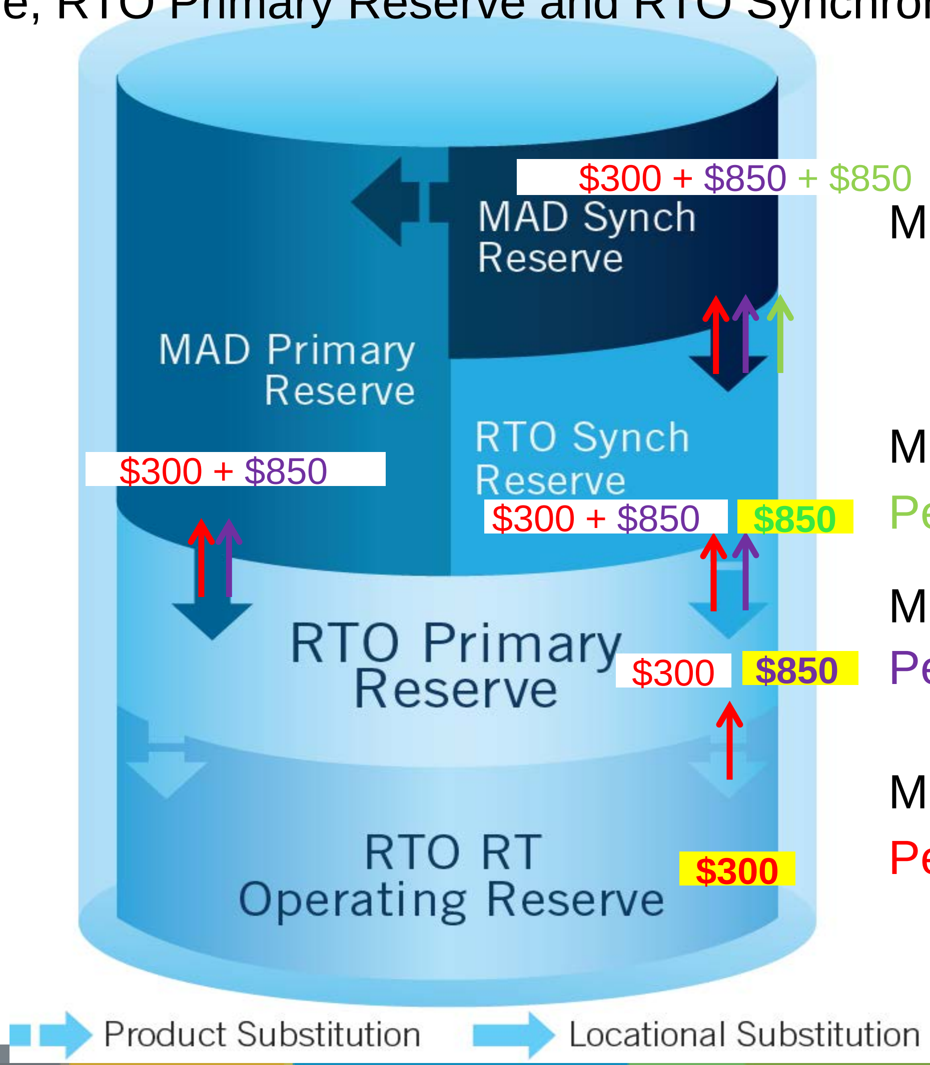
Min: $1150 Max: $2000

Min: $1150 Max: $1150
Penalty Factor = $850

Min: $300 Max: $300
Penalty Factor = $300

Assume RT Operating Reserve, RTO Primary Reserve and RTO Synchronized Reserve are short…

Min: $1150 Max: $1150



Min: $2000 Max: $2000

Min: $2000 Max: $2000

Penalty Factor = $850

Min: $1150 Max: $1150

Penalty Factor = $850

Min: $300 Max: $300

Penalty Factor = $300

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- Requirement
  - Based on the additional resources scheduled
    - ∑ (Economic min + 30 minute reserve capability)
  - DASR
    - Calculated by noon prior to the operating day and implemented in the Day Ahead Market
  - RTOR Requirement
    - 2300 the day prior for the off-peak (0000-0459)
    - 0400 the day of for the on-peak (0500-2359)

Additionally Scheduled Units

Unit	Eco Min	Eco Max	Ramp Rate (MW / Min)	30 min ramping capability	Additional Reserves Created (Eco Min + ramping capability)
A	500	1000	10	300	800
B	200	300	1	30	230
C	500	800	5	150	650
D	300	400	5	100 (limited by eco max)	400
Total	**1500**	**2500**			**2080**

Has enough been scheduled to meet the trigger?

If yes, this is how much is used to determine the requirement.

Example: Trigger for Clearing Secondary Reserve Market

Trigger:

Hot Weather Alert, Cold Weather Alert, Max Emerg Gen Alert, Weather / Environmental Emergency, Sabotage / Terrorism Emergency

AND/OR

We've scheduled at least an additional .5% of forecasted peak load outside of the DA/RAC run based on the eco mins of the scheduled units

Example:

- Peak Load Forecast = 160,000
- DASR Requirement = 6.27% of peak load forecast = 10,032 MW
- Threshold for triggering reserve req = .5% * 160,000 = 800 MW
- Amount additionally scheduled = 1,500 MW (sum of ecomins on additionally scheduled units)
- Trigger Secondary Reserve requirement? *YES*

DASR Requirement Increase:

- 6.27% of 160,000 MW peak = 10,032 MW
- Sum of (eco min + DA Default RR * 30) of units scheduled outside DA market and RAC run
  - 2,080 MW

Updated DASR Requirement = 6.27% of peak load plus above sum = 12,112 MW

- DASR scheduled includes capacity to meet
  - Average forced outage rates
  - Average load forecast error
  - 10-minute reserve capability

- 10,032 MW of DASR scheduled based average errors
  - 3,376 MW for the 2.11% of LFE
  - 6,656 MW for the 4.16% eFOR

6.27%

- Between LFE and eFOR there are 8,032 MW of “error”

- This leaves 2,000 MW of "excess" DASR scheduled on the system

- PJM proposes the requirement for RTOR to be

$$\frac{\text{Primary Reserve Requirement} + \sum(\text{Economic min} + \text{30 minute reserve capability})}{\text{RTOR Requirement}}$$

- In this example

$$\frac{2{,}063\ \text{MW} + 2{,}080\ \text{MW}}{4{,}143\ \text{MW}}$$

Why?

- Trying to estimate the LFE and eFOR to be something other than what they are on average will likely not be accurate
  - If PJM had a better estimation than the average we would use it to set the DASR requirement everyday.

- The addition to the Primary Reserve requirement is done because Primary Reserves are a subset of Operating Reserves
  - Total amount of 30-minute reserve capability subject to some amount being usable within 10-minutes

RTOR Requirement When Additional Resources Call After DA and RAC

- If resources were added after the Day Ahead commitment and outside of the RAC run then those resources would be included in the RTOR requirement based on the same criteria
- Assume we added another 1000 MW (sum of ecomins and 30-minute reserve capability.
- Now the RTOR requirement would be

	2,063 MW
+	2,080 MW
+	1,000 MW
	5,143 MW

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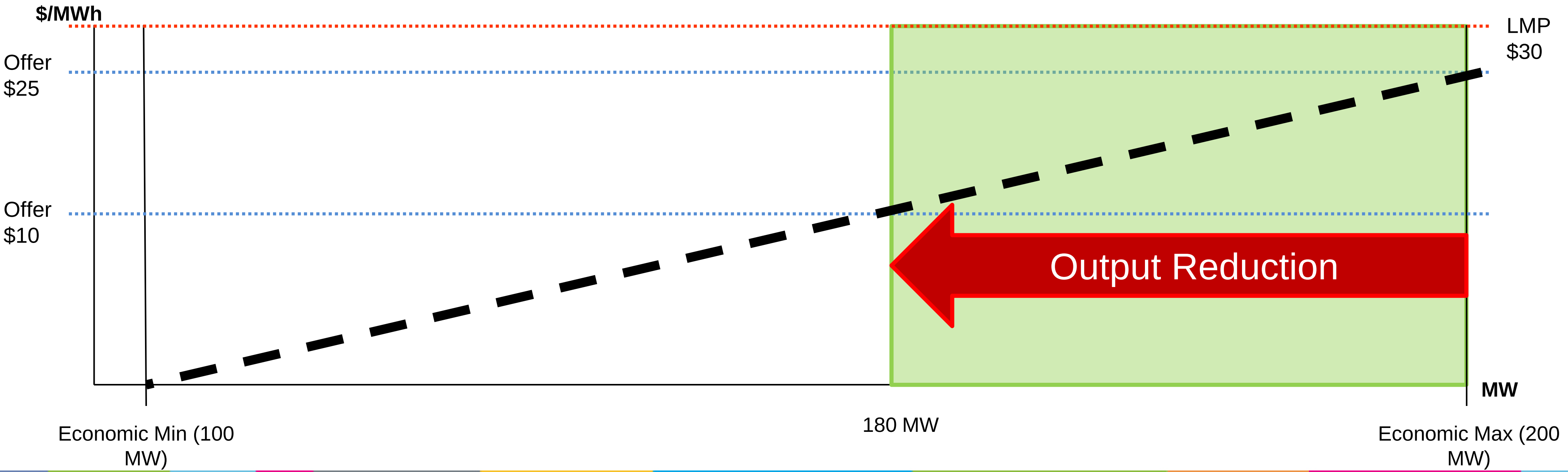
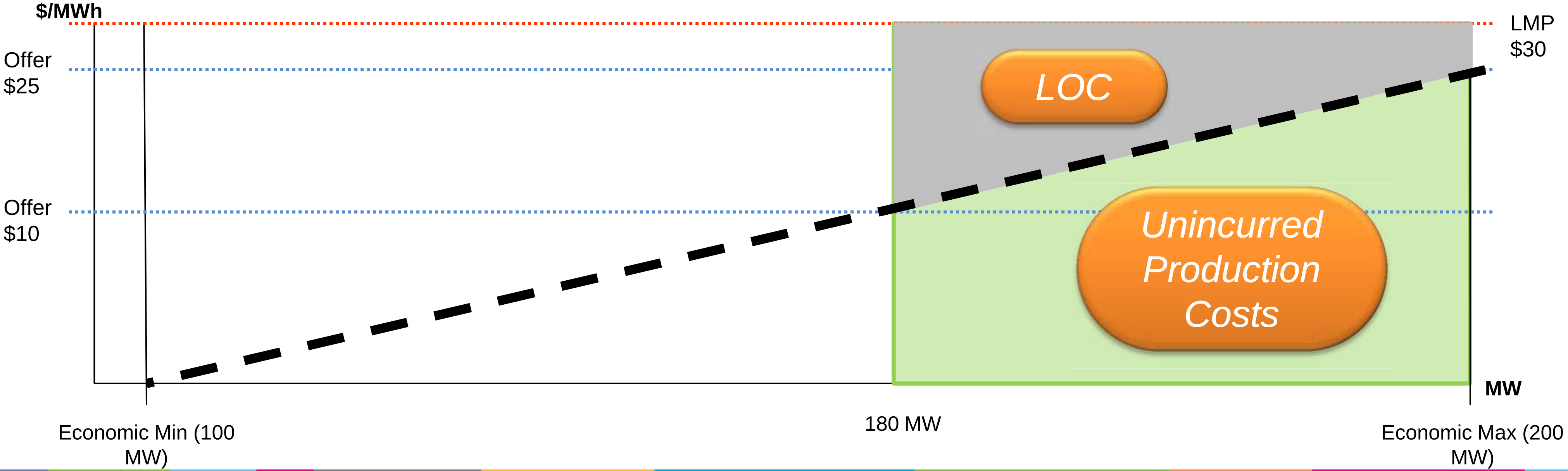
Lost Opportunity Cost

- Resource economic @ 200 MW but reduced to 180 MW to provide reserves
- Resource loses its opportunity to provide energy and receive energy revenues
- The reserve market must account for this



- Lost Opportunity Cost (LOC)
  - For reserves, the lost revenues as a result of operating uneconomically to provide a reserve service other than energy
  - The larger the difference between the resource offer and LMP, the higher the opportunity cost and the less economic the resource is for reserves.



- LOC is included in the 5-minute market clearing prices for reserves and is recalculated again for final settlement based on final values.

- Incorporating LOC into the reserve market clearing prices ensures resources are indifferent to providing energy or reserves.

- It provides a strong incentive for resources assigned reserves to not follow high energy prices.

LOC Calculation Example

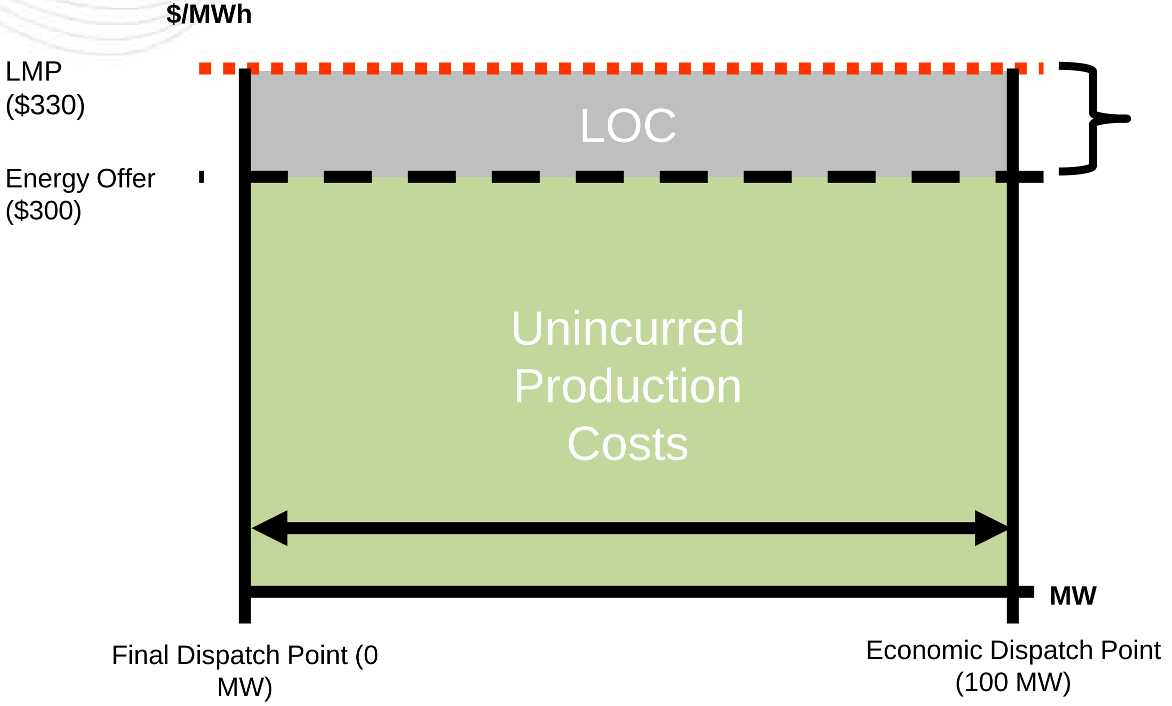
Sample Unit Parameters

RT LMP: $330/MWh

Eco Min: 100
Eco Max: 100

Energy Offer Curve

MW	Price
100	$300



LOC = $330 - $300 = $30/MWh

Market clearing price will be at least $30/MWh to account for the lost revenues of this resource in the energy market.

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- The Secondary Reserve Market clearing is a joint optimization between energy, regulation, synchronized reserves, non-synchronized reserves and secondary reserve products
- The goal of the optimization is to minimize the total cost of producing energy, regulation, and reserves
- Resources can be committed for secondary reserve if they are committed for energy, tier 2 synchronized reserve, non-synchronized reserve during the same interval
- Resources cannot be committed for secondary reserve if they are committed for regulation during the same interval

Secondary Reserve Market Timeline

- Secondary Reserves are cleared and priced on a 5 minute basis
  - Secondary reserve estimates will be conducted 60 minutes prior to the top of the operating hour, with results posted to public section of eMKT 30 minutes prior to the top of the hour
  - Resource level Secondary reserve market clearing and commitment will be conducted every 5 minutes, with results communicated via ICCP link
  - Five minute prices will be made available via eData

Single Product Example: Load = 2600 MW, Reserve Req = 100 MW

Resource	Energy Offer ($/MWh)	Minimum (MW)	Maximum (MW)	Output (MW)	Reserve Capability (MW/30-minutes)	Opportunity Cost ($/MWh)	Reserve Assignment (MW/30-minutes)
A	10	100	500	500	20	0	0
B	20	100	500	500	40	0	0
C	30	100	500	500	60	0	0
D	**50**	**100**	**500**	**495**	**70**	**5**	**5**
E	**55**	**100**	**500**	**405**	**30**	**0**	**30**
F	70	100	500	100	25	0	25
G	80	100	500	100	40	0	40
Totals			**3500**	**2600**	**285**		**100**

	$/MWh
LMP	55.00
Reserve MCP	5.00

Assume offers for Reserves are $0

- In this scenario:
  - Unit E is marginal for energy
    - If the load increased by 1 MW, the least expensive resource to get that MW from would be resource E. It would not impact the reserve assignment on unit E as it is not capacity constrained. Using resource D, although incrementally cheaper, would cause a reserve shortage.
    - The LMP = $55/MWh. The offer of Unit E.
  - Unit D is marginal for reserves
    - If the reserve requirement increased by 1 MW, the least expensive resource to get that MW from would be resource D. Resource D would have to have its output reduced by an additional MW to make room for the additional reserves. That MW of energy would be replaced by dispatching resource E up another MW.
    - As a result, the reserve clearing price is $5/MWh. This is the energy offer of resource E minus the energy offer of resource D ($55/MWh - 50/MWh = $5/MWh)

Single Product Example : *Load = 3300 MW*, Reserve Req = 100 MW

Resource	Energy Offer ($/MWh)	Minimum (MW)_	Maximum (MW)	Output (MW)	Reserve Capability (MW/30-minutes)	Opportunity Cost ($/MWh)	Reserve Assignment (MW/30-minutes)
A	10	100	500	500	20	0	0
B	20	100	500	500	40	0	0
C	30	100	500	500	60	0	0
D	**50**	**100**	**500**	**495**	**70**	**30**	**5**
E	55	100	500	470	30	25	30
F	70	100	500	475	25	10	25
G	**80**	**100**	**500**	**360**	**40**	**0**	**40**
Totals			**3500**	**3300**	**285**		**100**

	$/MWh
LMP	80.00
Reserve MCP	30.00

Assume offers for Reserves are $0

- In this scenario:
  - Unit G is marginal for energy
    - If the load increased by 1 MW, the least expensive resource to get that MW from would be resource G. Resource D has the lowest incremental cost but dispatching it up for energy would create a reserve shortage. Therefore, unit G sets LMP.
    - The LMP = $80/MWh. The offer of Unit E.
  - Unit D is marginal for reserves
    - If the reserve requirement increased by 1 MW, the least expensive resource to get that MW from would be resource D. Resource D would have to have its output reduced by an additional MW to make room for the additional reserves. That MW of energy would be replaced by dispatching resource G up another MW.
    - As a result, the reserve clearing price is $30/MWh. This is the energy offer of resource G minus the energy offer of resource D ($80/MWh - 50/MWh = $30/MWh)

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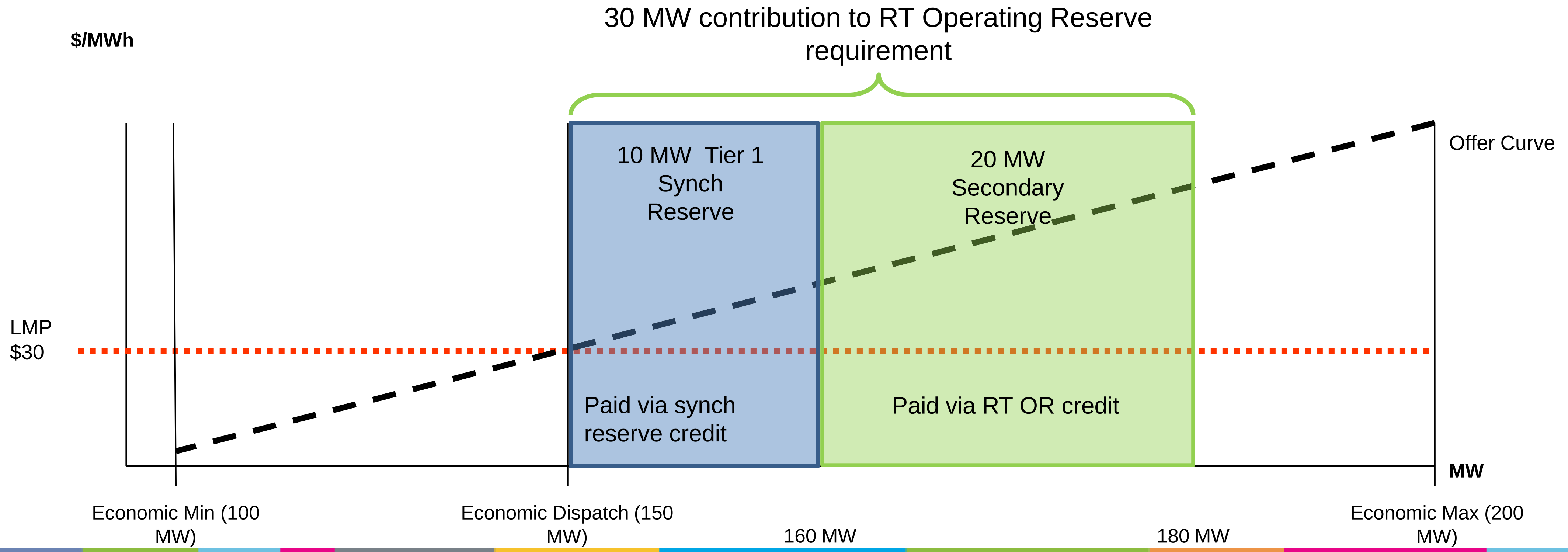
Settlement – Resource Specific

- Any resource providing Primary Reserve (SR or NSR) is by default also providing Operating Reserves
- Because the cost allocation for the reserve products are different, settlement must assign certain MW ranges and opportunity costs to certain products
- PJM will assign these MWs based on response time
  - The cost of the MW attainable within the first 10 minutes will be allocated to SR or NSR (depending on on/offline state)
  - The cost of the MW attainable within minutes 11-30 will be allocated as secondary reserve

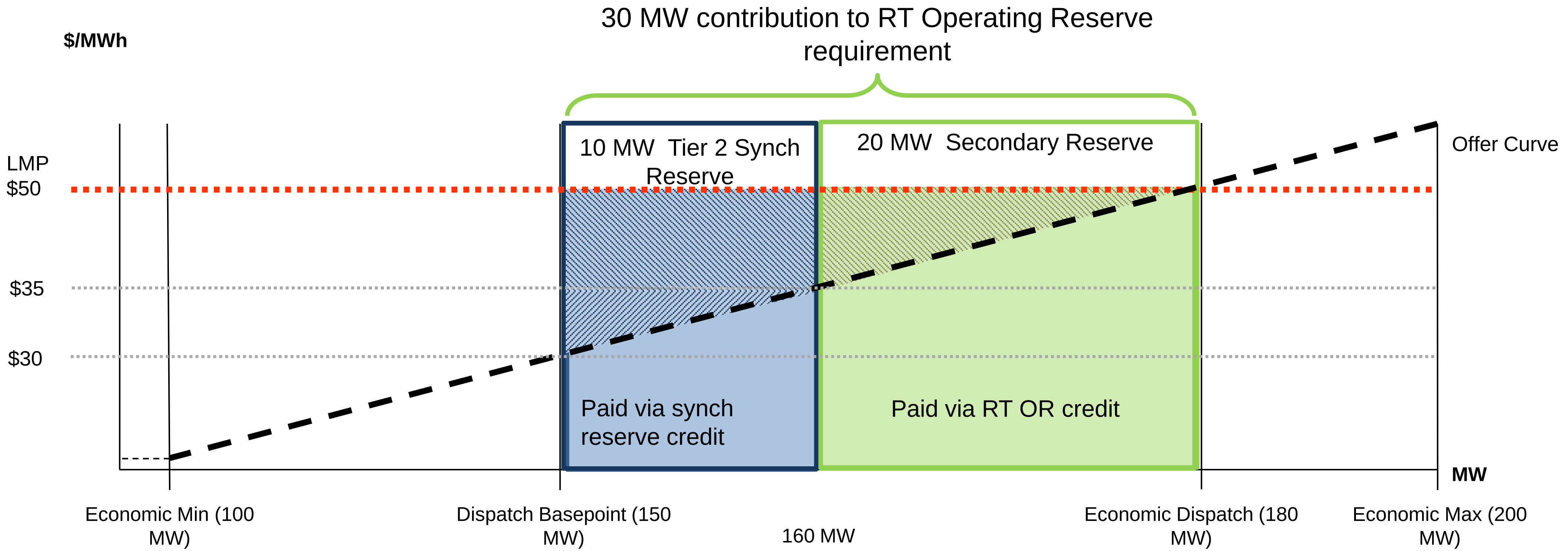
Accounting of Tier 1 and RT OR From the Same Unit

- Unit A has the following characteristics:
  - Eco Min: 100 MW
  - Eco Max: 200 MW
  - Ramp Rate: 1 MW / Minute (30 MW in 30 minutes)
  - Economic Dispatch: 150 MW



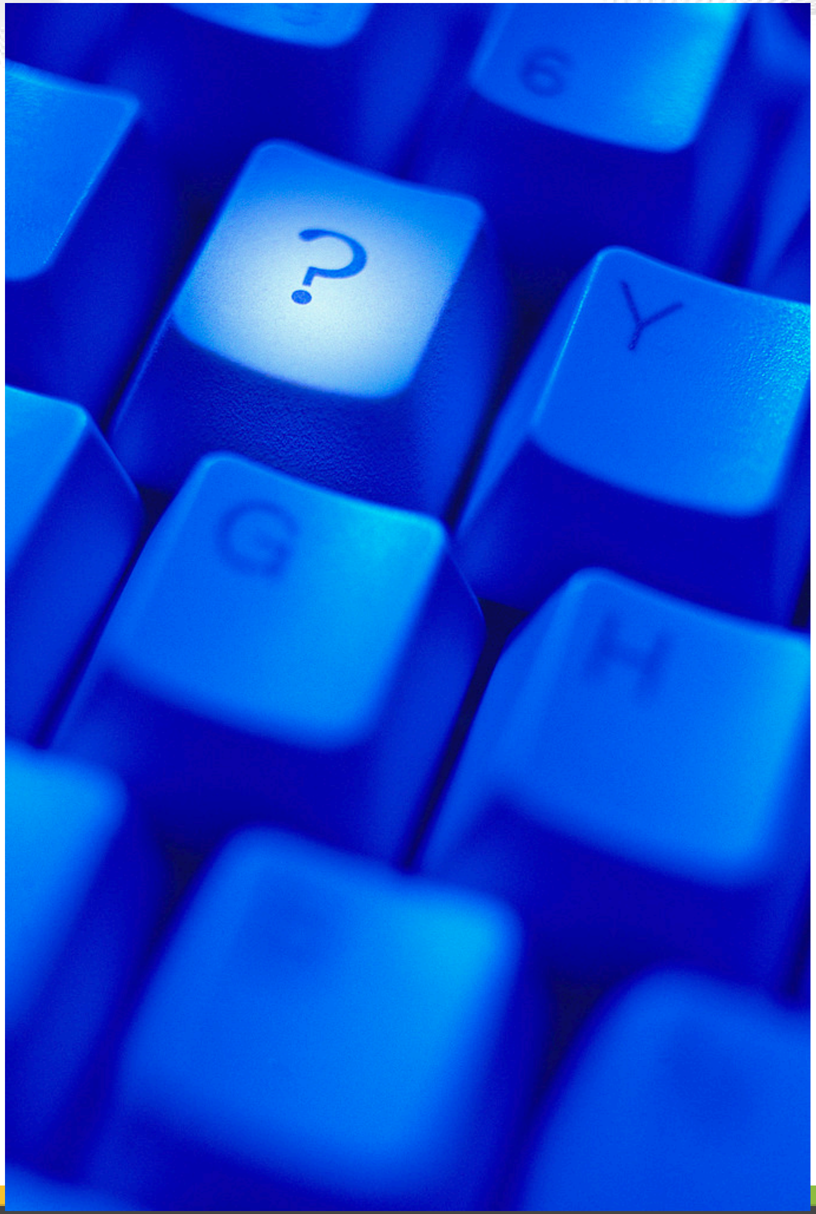
Accounting of Tier 2 and RT OR From the Same Unit

- Unit A has the following characteristics:
  - Eco Min: 100 MW
  - Eco Max: 200 MW
  - Ramp Rate: 1 MW / Minute (30 MW in 30 minutes)
  - Economic Dispatch: 150 MW



Importance of Assigning LOC to a Product

- The determination of what market the opportunity cost for a resource is assigned to is important for two reasons:
  - If a resource's cost is not covered by the clearing price it will receive an uplift payment that will be allocated via the cost allocation mechanism for the specific reserve product.
  - If a resource profits in a reserve market, those revenues offset the Balancing Operating Reserve credit it would be eligible for.
- If the cost allocation for the SR, NSR and RTSR markets were the same, opportunity cost could be treated uniformly across all markets and greatly simplify settlements.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