



LMP Calculation and Uplift

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January 29, 2018

- Review fundamentals of locational marginal pricing (LMP) and uplift
- Review simple locational marginal pricing and uplift examples

Three costs compose a resource's offer:

Start-up cost
(\$/start)

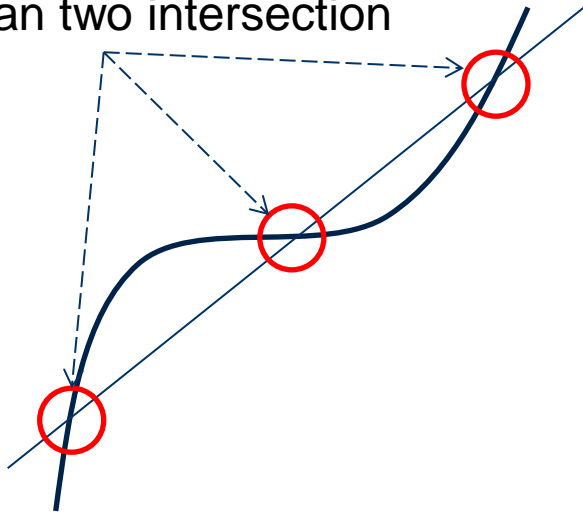
Incremental
energy cost
(\$/MWh)

No-load cost
(\$/hour)

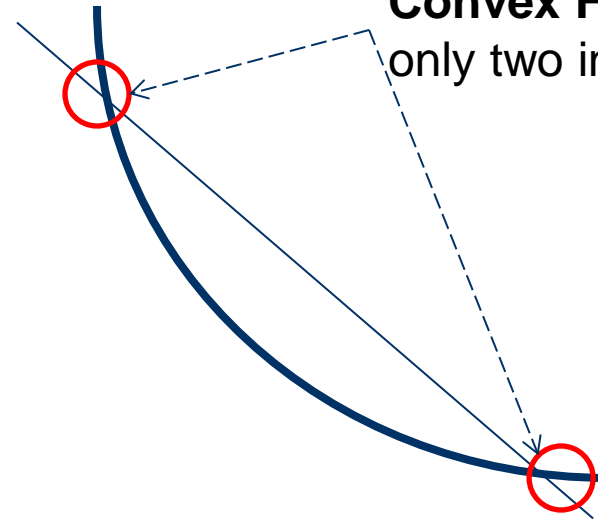
Convexity refers to the curvature of a function.

A function is convex if any straight line you draw across the function does not intersect the function in more than two places.

Non-Convex Function –
more than two intersection
points



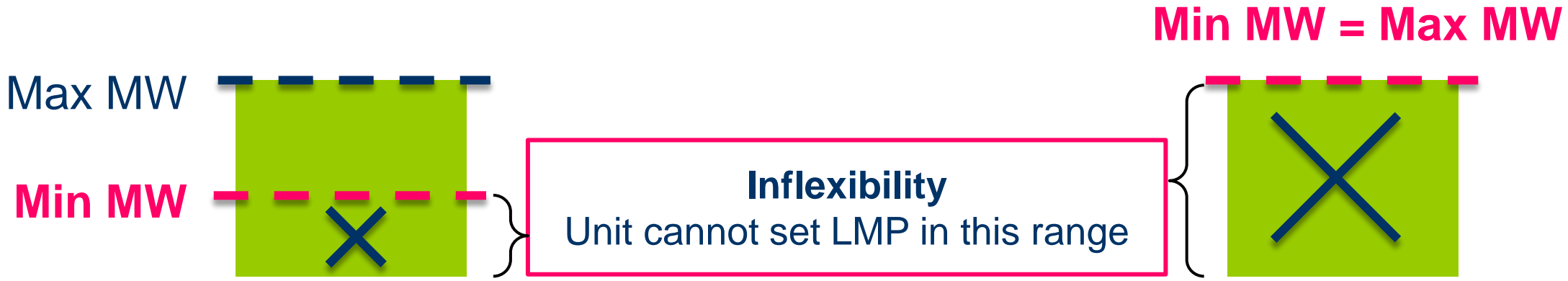
Convex Function –
only two intersection points



- LMP is the cost of optimally supplying an increment (or decrement) of load at a particular location while satisfying all operational constraints.
 - One can think of the LMP as the change in total production cost to deliver an increment of load at a location using the offers submitted to the market.
 - The commitment cannot change in response to an increment in load.
- LMPs are produced as a result of economic dispatch with the commitment fixed.

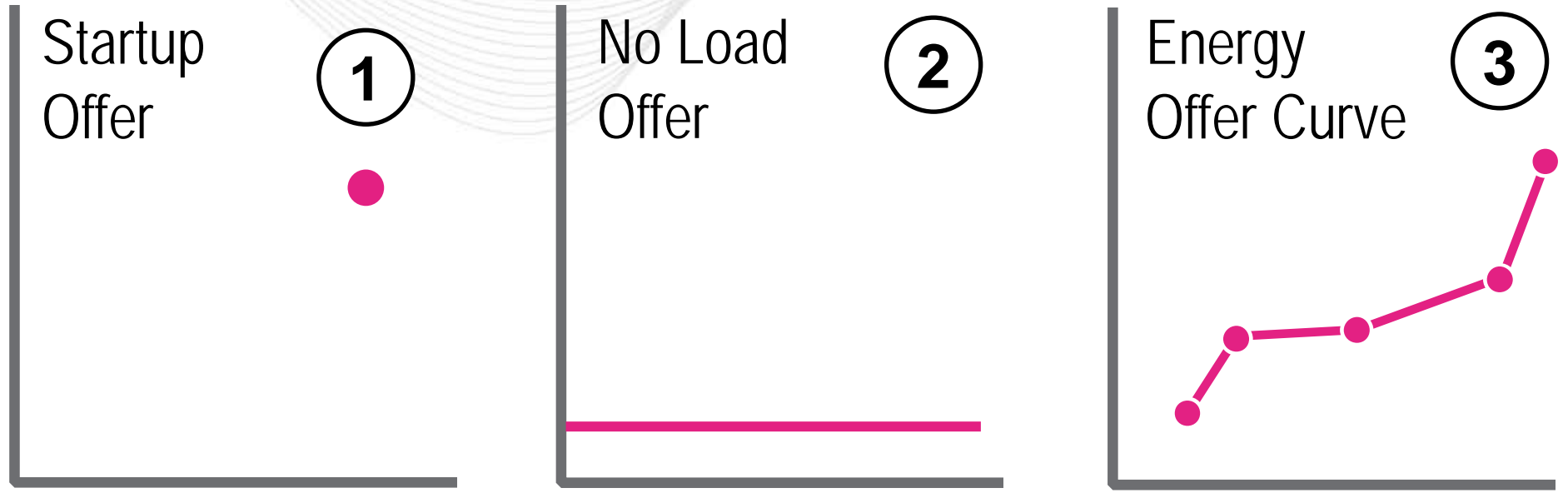
- PJM currently uses locational marginal pricing
 - Initially chosen for simplicity in concept and implementation
- It ignores the presence of non-convexities in its price-setting logic and assumes that certain units (often referred to as inflexible units), or certain output ranges of units, are ineligible to set price when they fail the convex condition
 - Many units have non-convex total cost curves because when their output decreases below their minimum operating limits, their incremental costs rise
 - To address this, units submit offers starting at the MW output at which their incremental costs become monotonically increasing

- In general, resources that are online and being dispatched by PJM can be relied upon to serve the next MW of load (eligible to set LMP)
Excludes: block loaded units, interchange transactions, among others
- From these resources, only those MW above the minimum operating limit may set LMP



What Part of a Resource's Offer is Used in LMP?

Three Part Offer



Used In
Commitment Decisions
Dispatch and LMP

\$/Start



\$/Hour



\$/MW



Costs not included in LMP may be recovered via uplift

- For resources that are “out of the money”, any portion of a resource’s incremental cost that exceeds LMP
 - Units that are needed for only a portion of their minimum output
 - “Inflexible” units that are needed to serve load
- Generator start up and no load costs / DR Shutdown cost

$$\text{Uplift} = \text{Make-Whole Payments} + \text{Lost Opportunity Cost}$$

- **Make-whole payments:** Occur when a resource's revenue cannot cover its total offer costs, including fixed costs (start-up and no-load costs).
- **Lost opportunity cost:** Occurs when a resource's dispatch point is not profit maximizing.

Additional Uplift Drivers

Unit Parameters

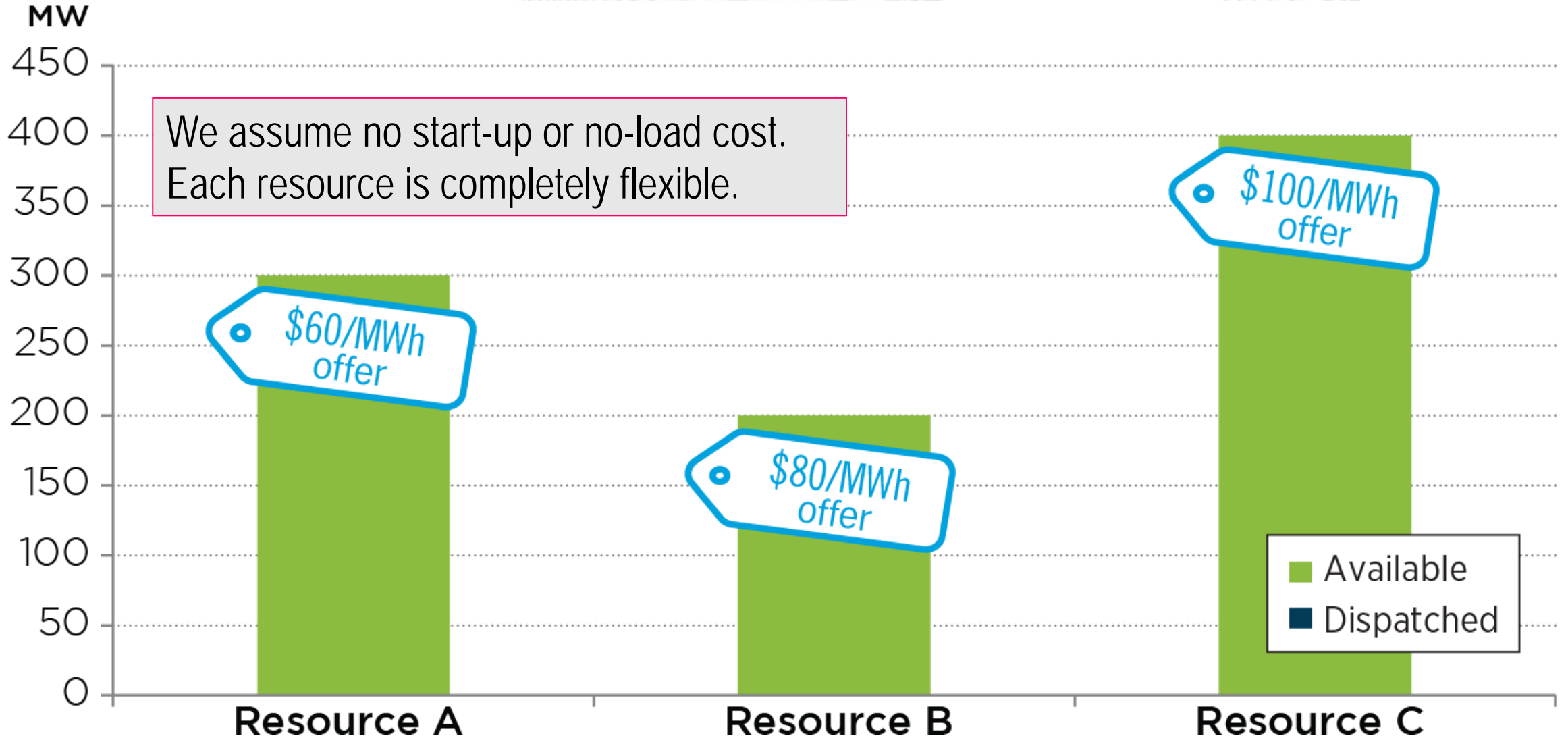
Long lead time units

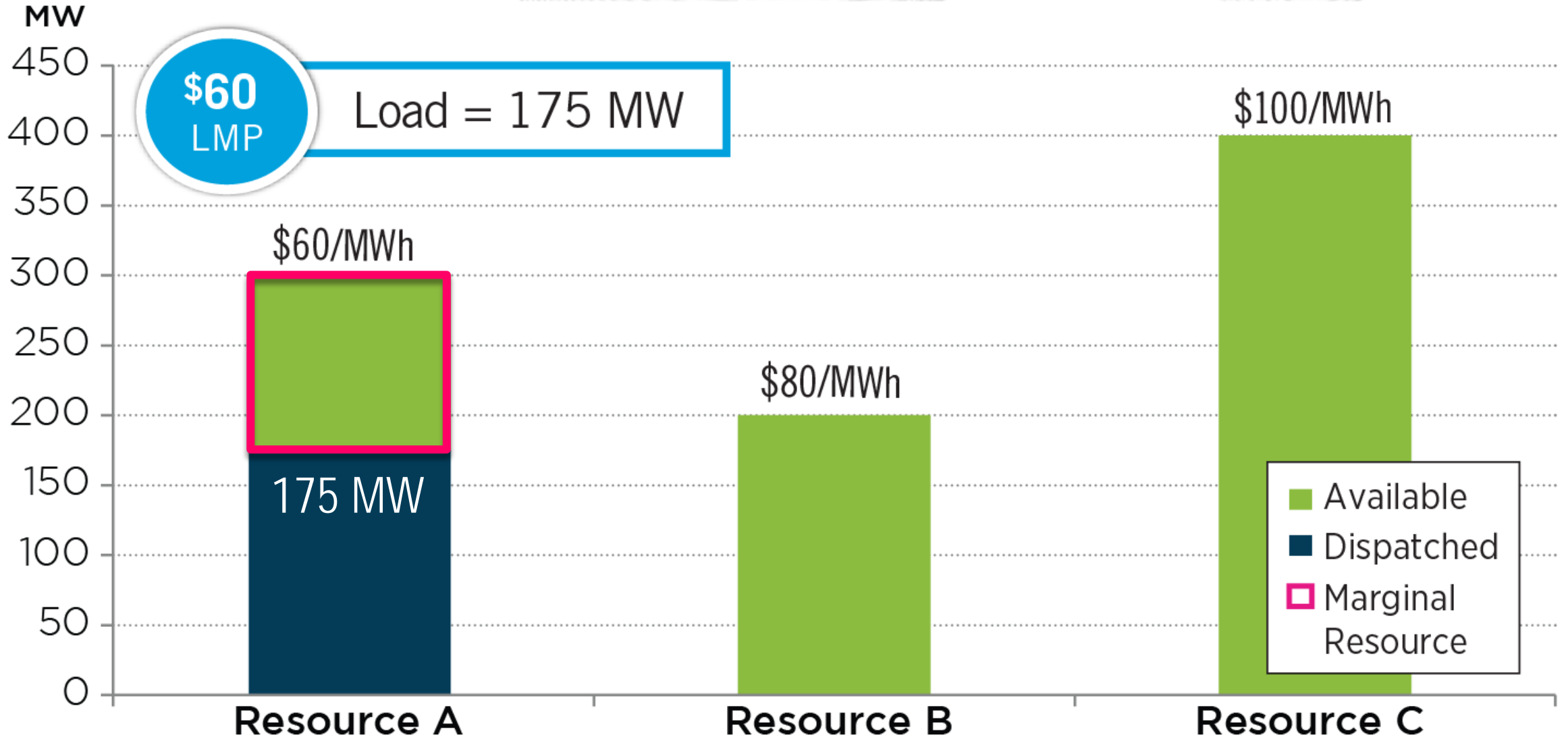
Load, interchange and outages under or over forecast

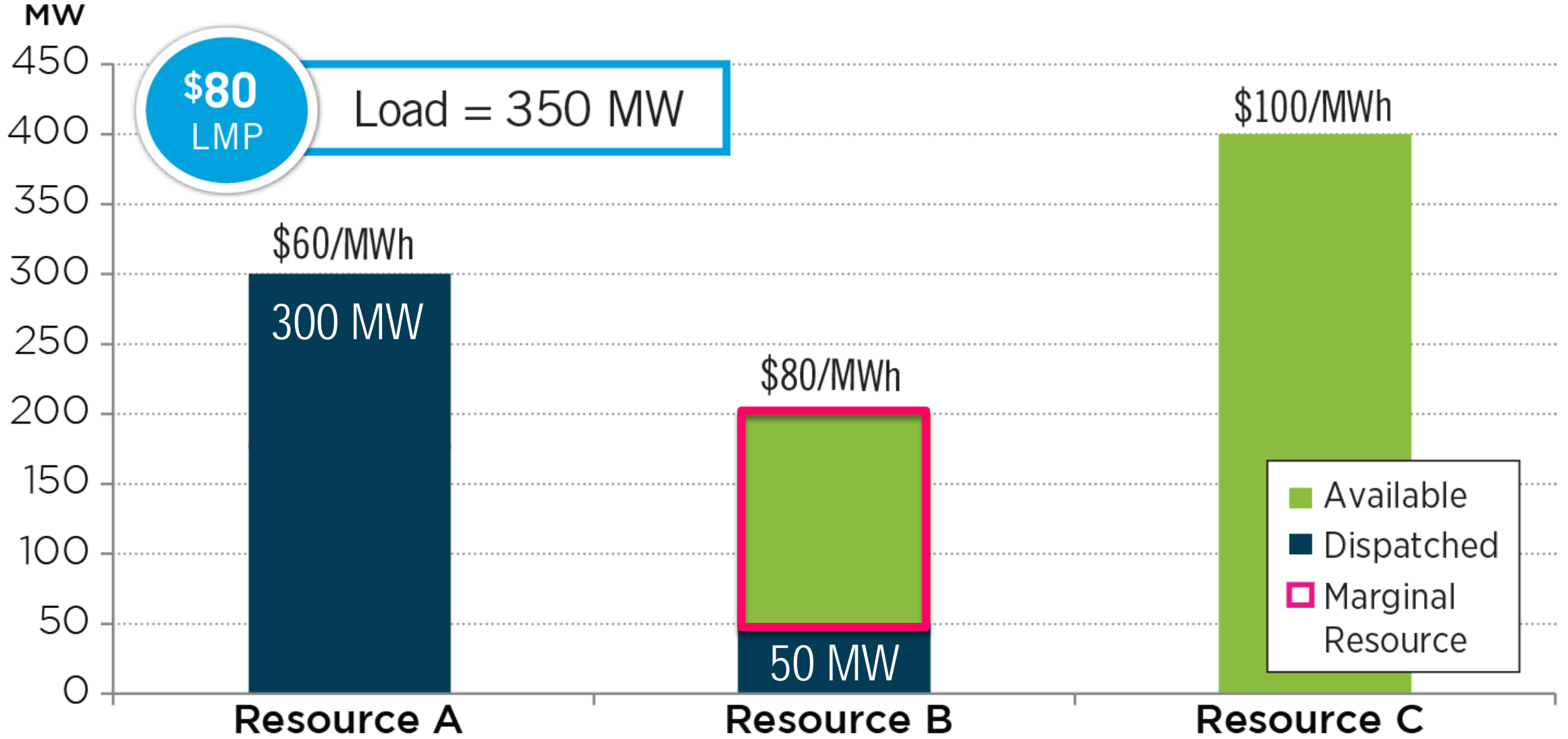
Reactive constraints

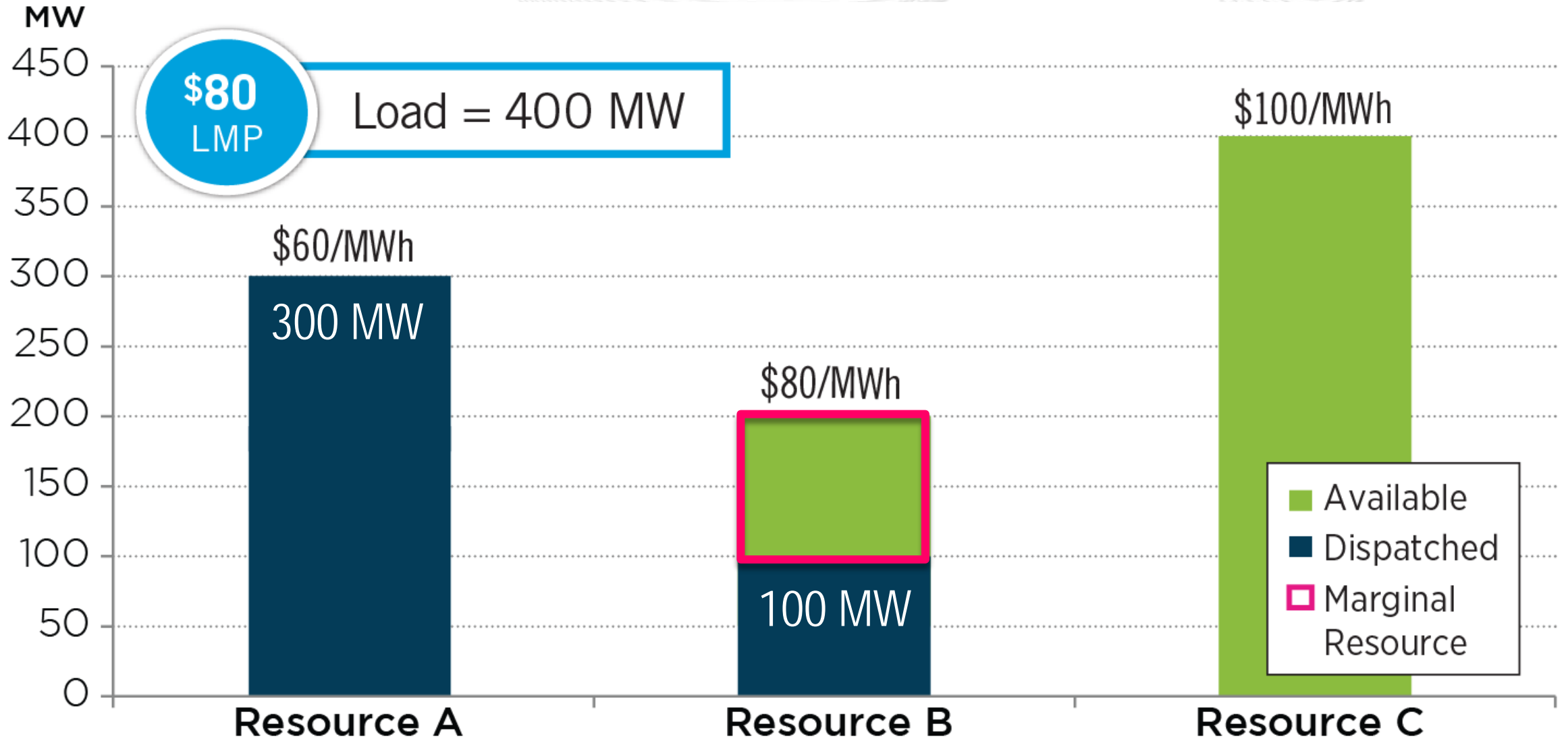
LMP AND UPLIFT EXAMPLES

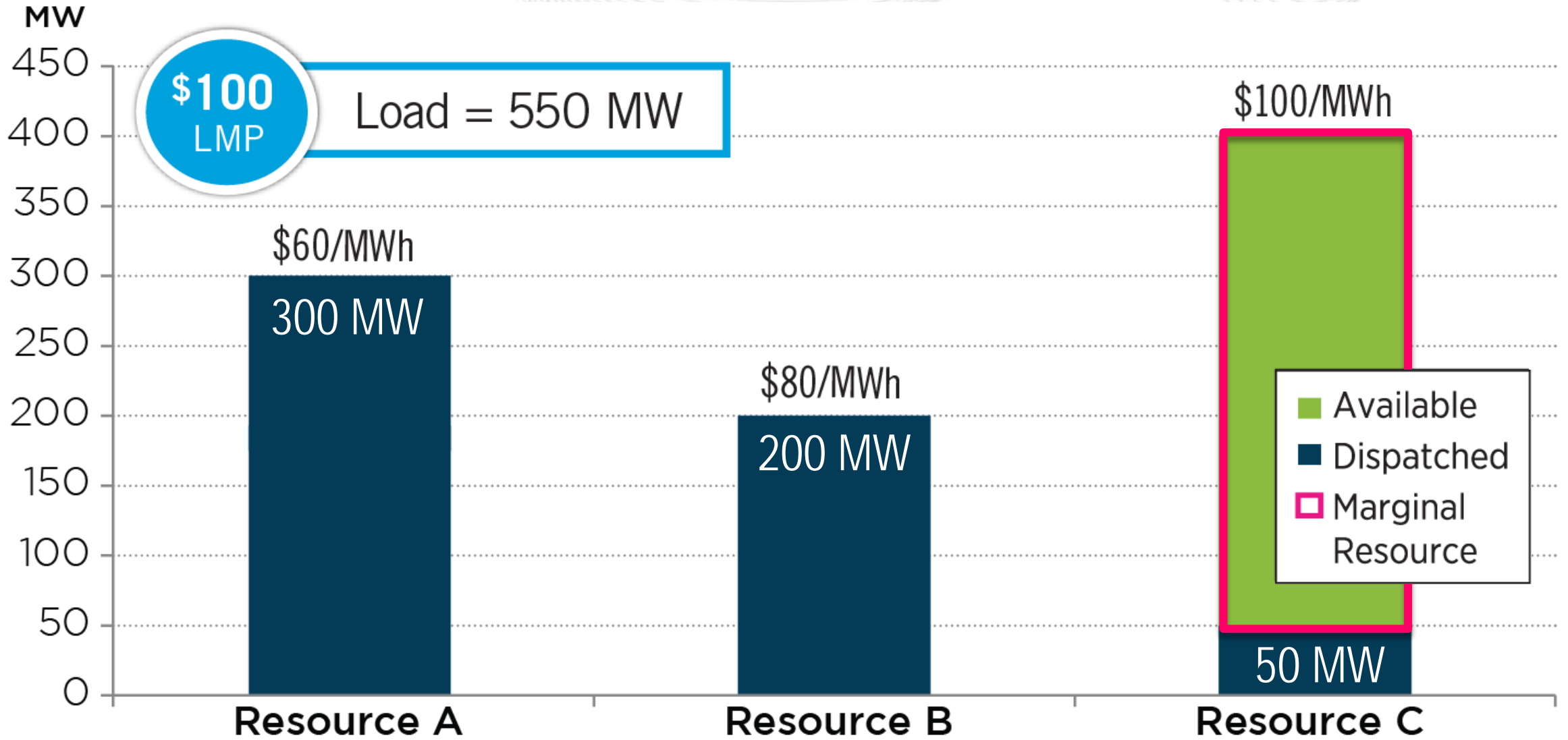
Set 1

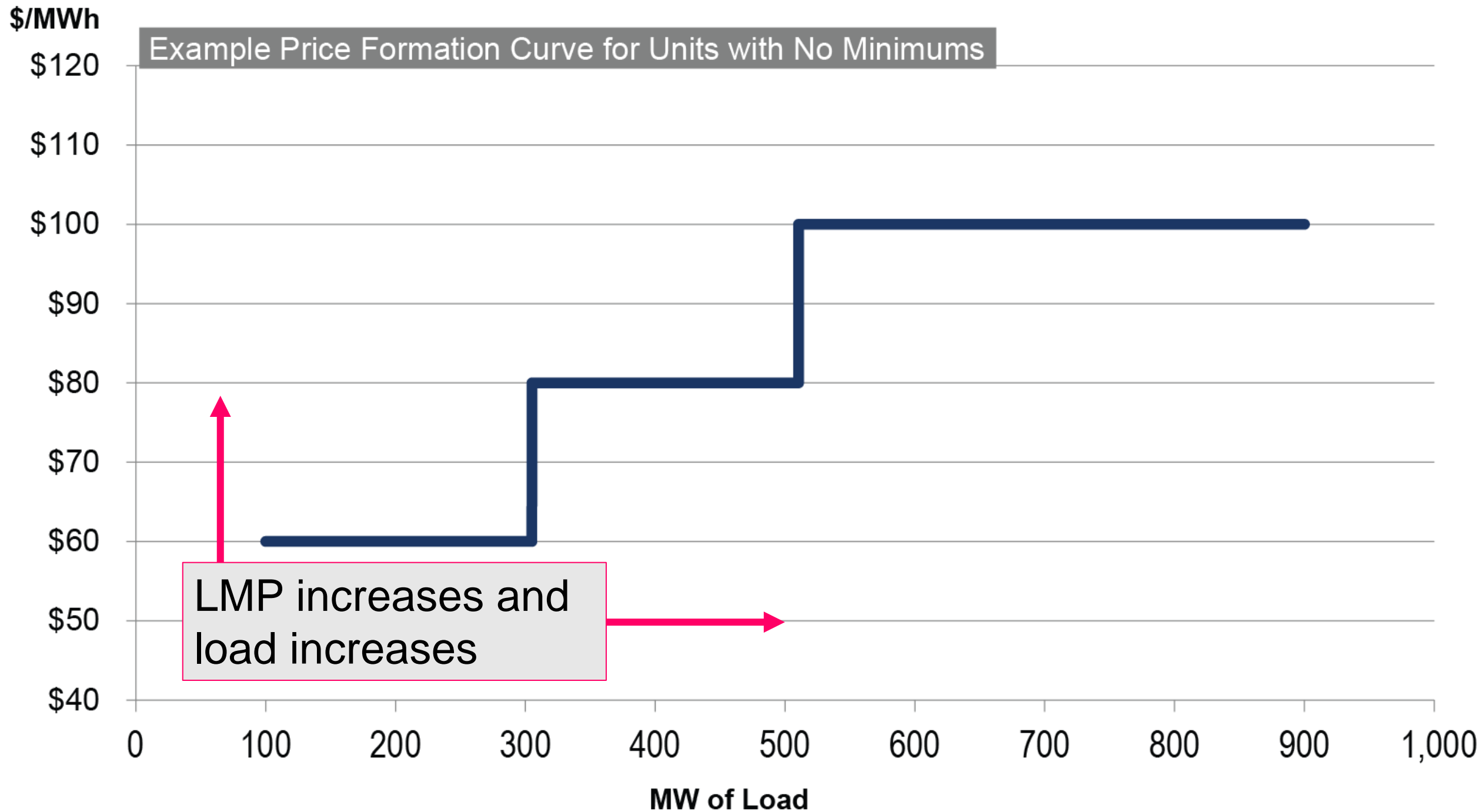






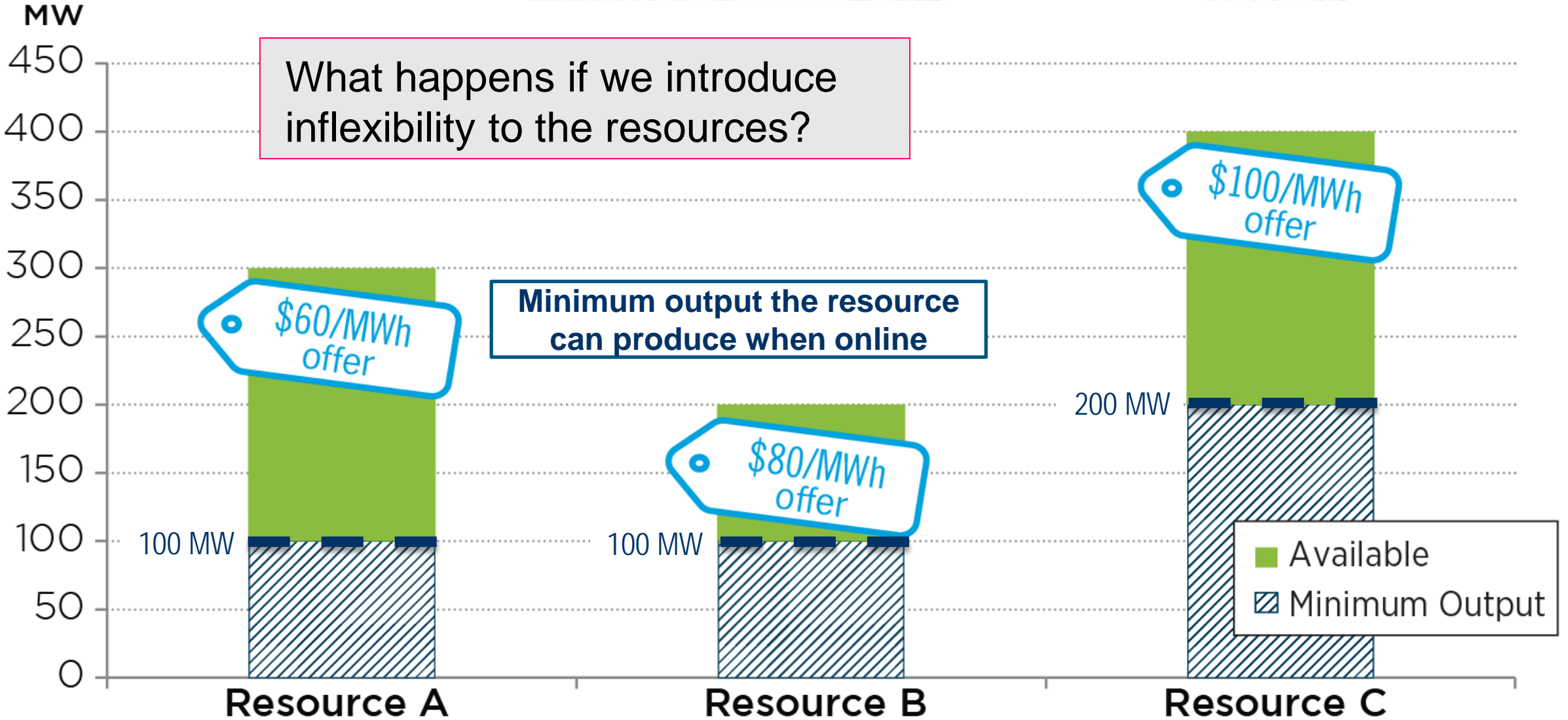




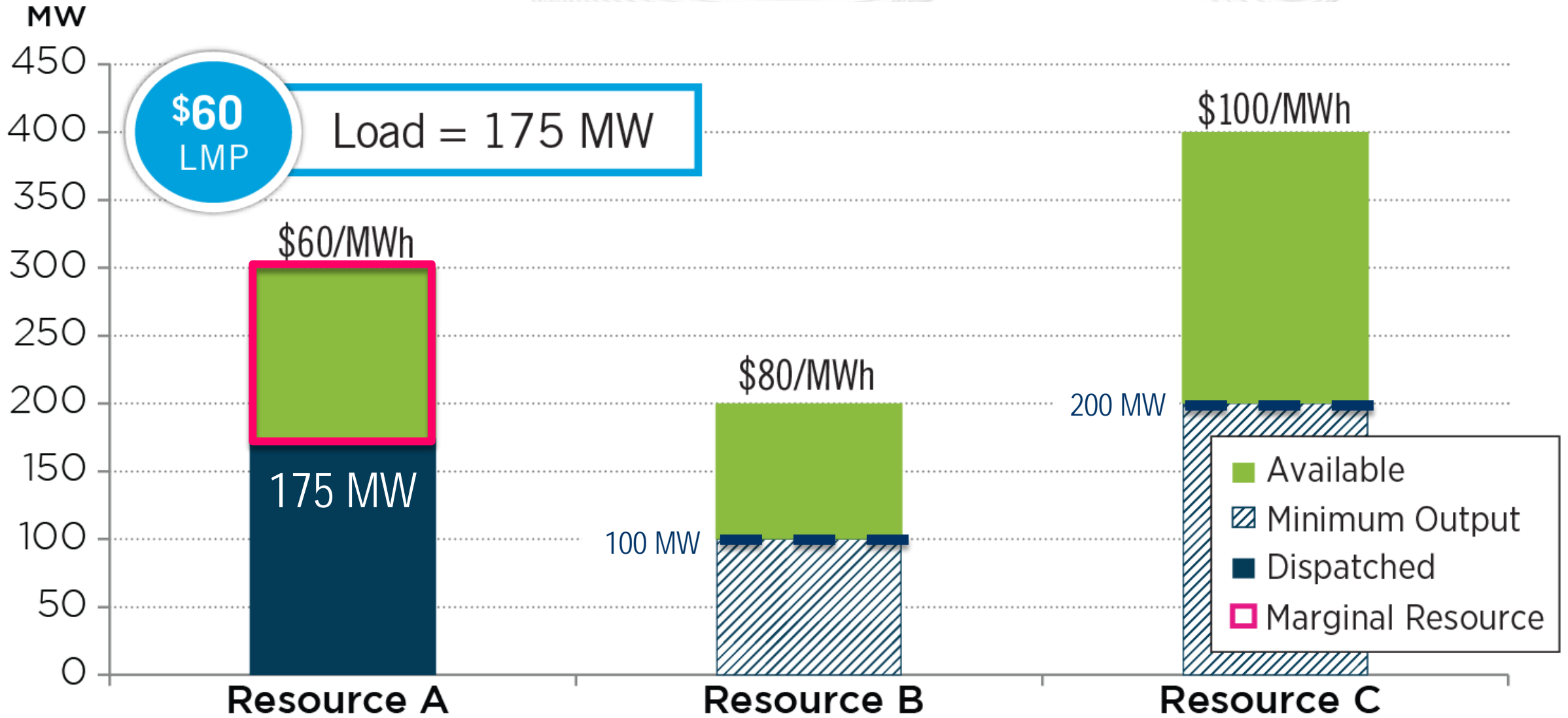


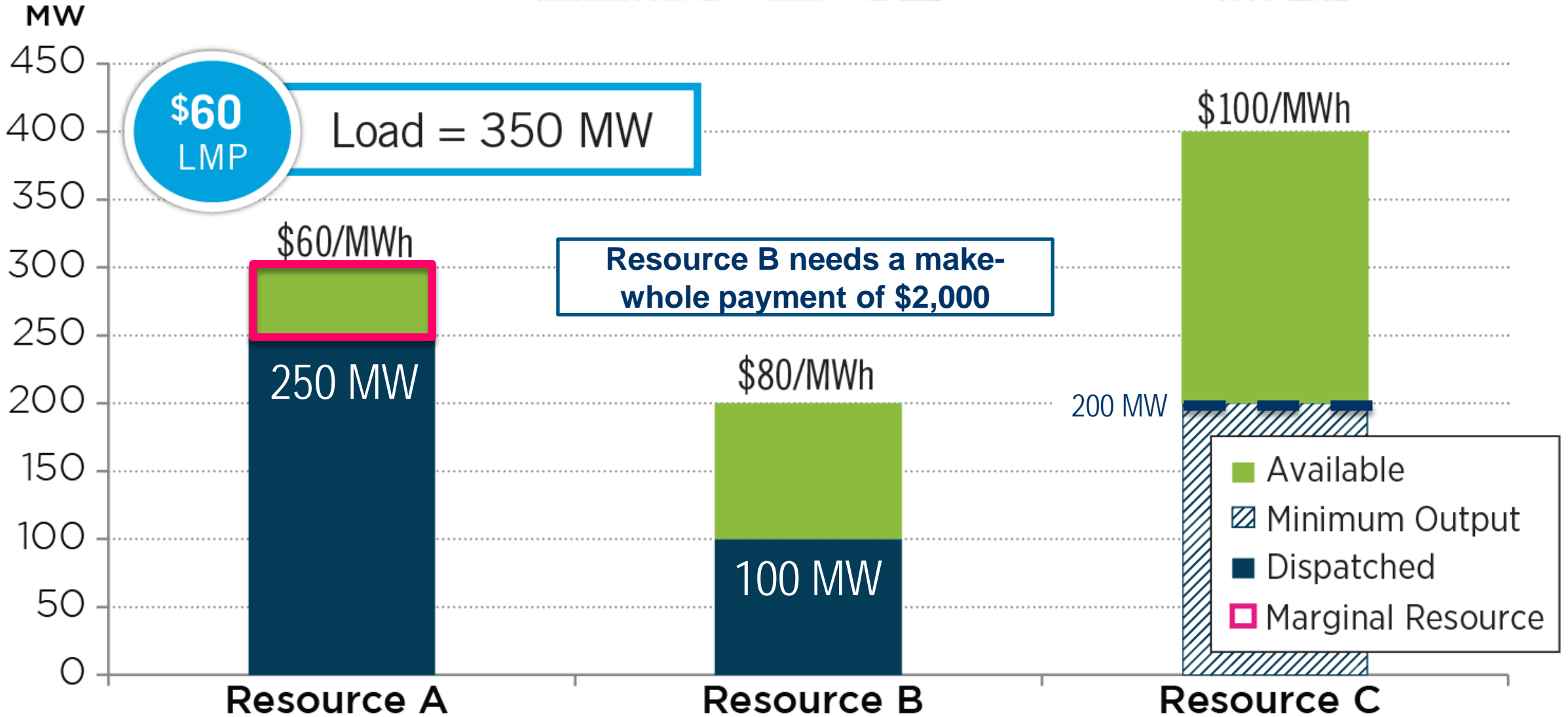
What happens if we introduce inflexibility to the resources?

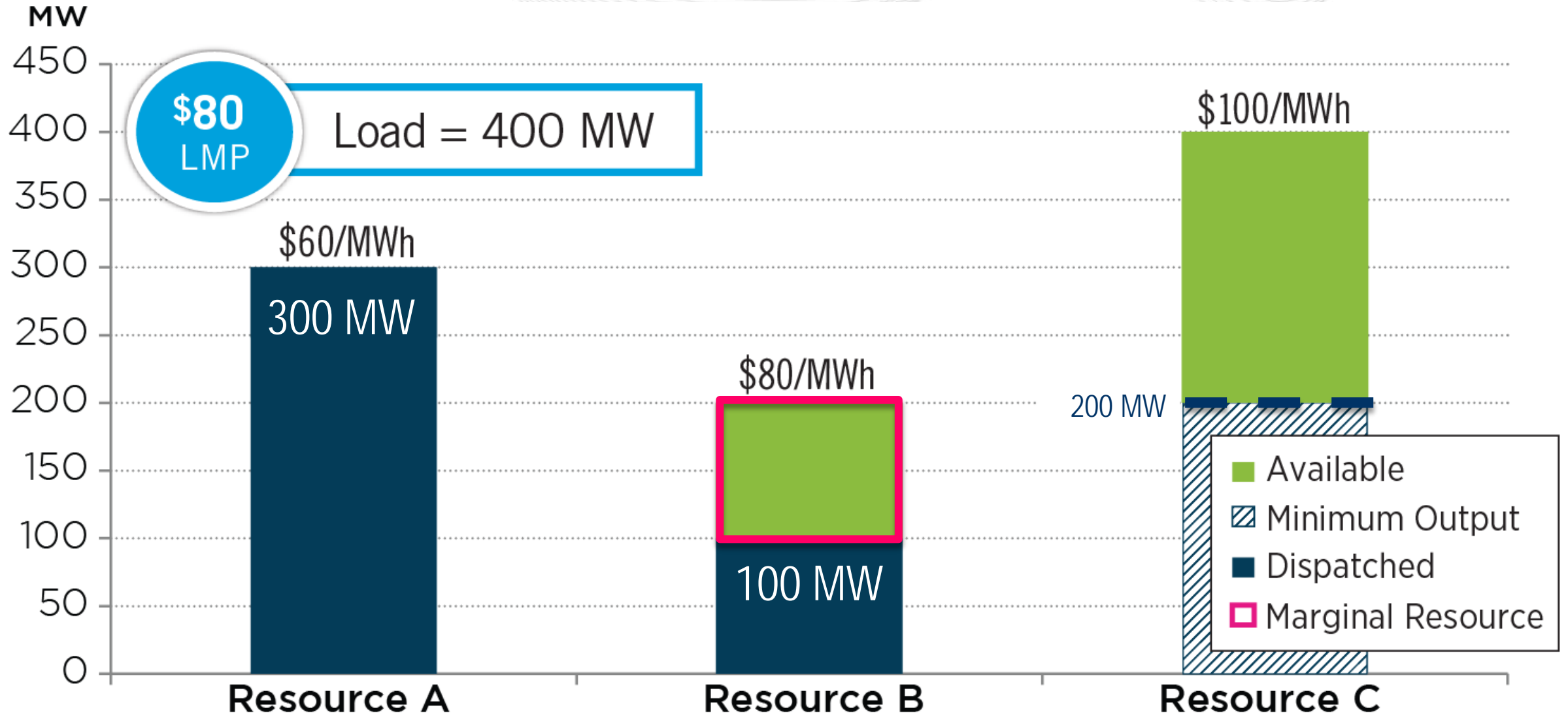
Minimum output the resource can produce when online

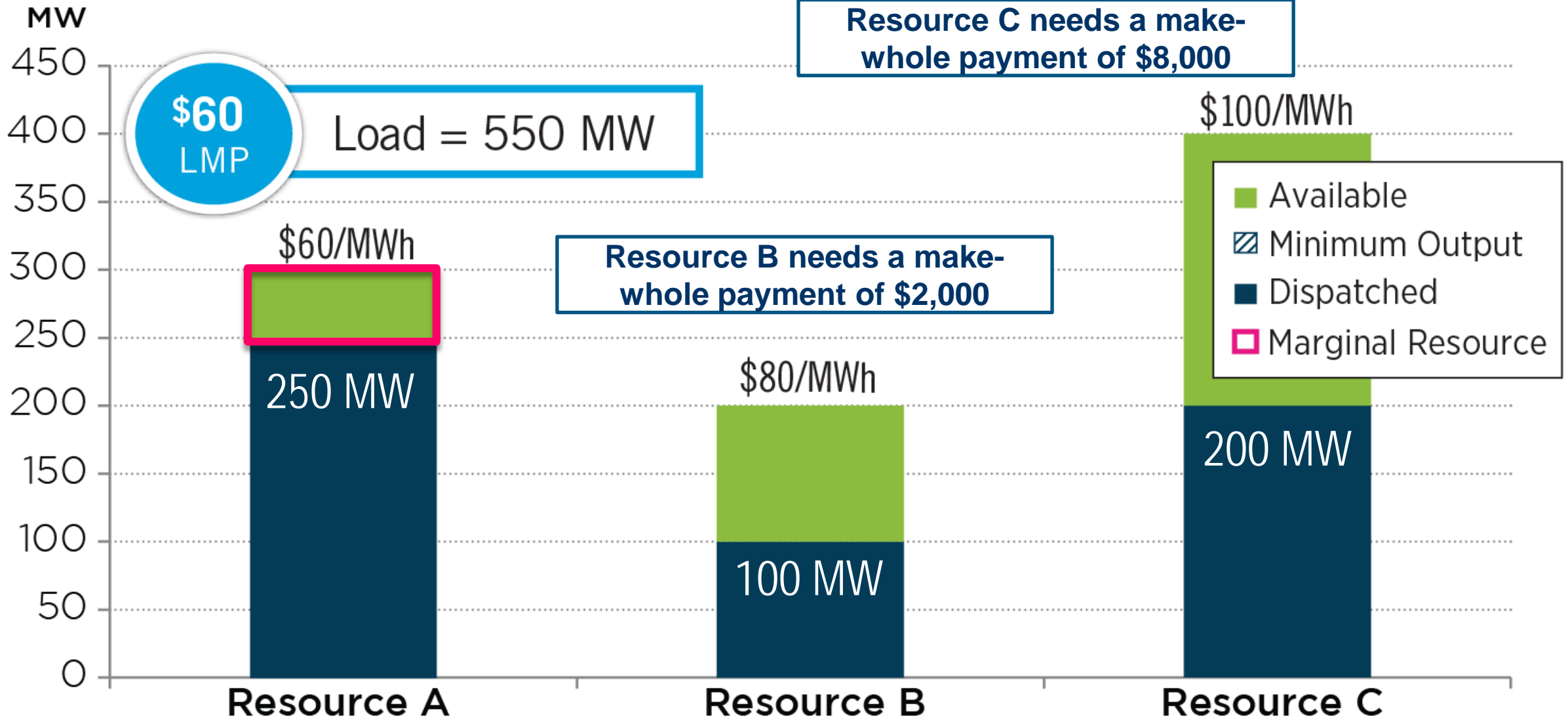


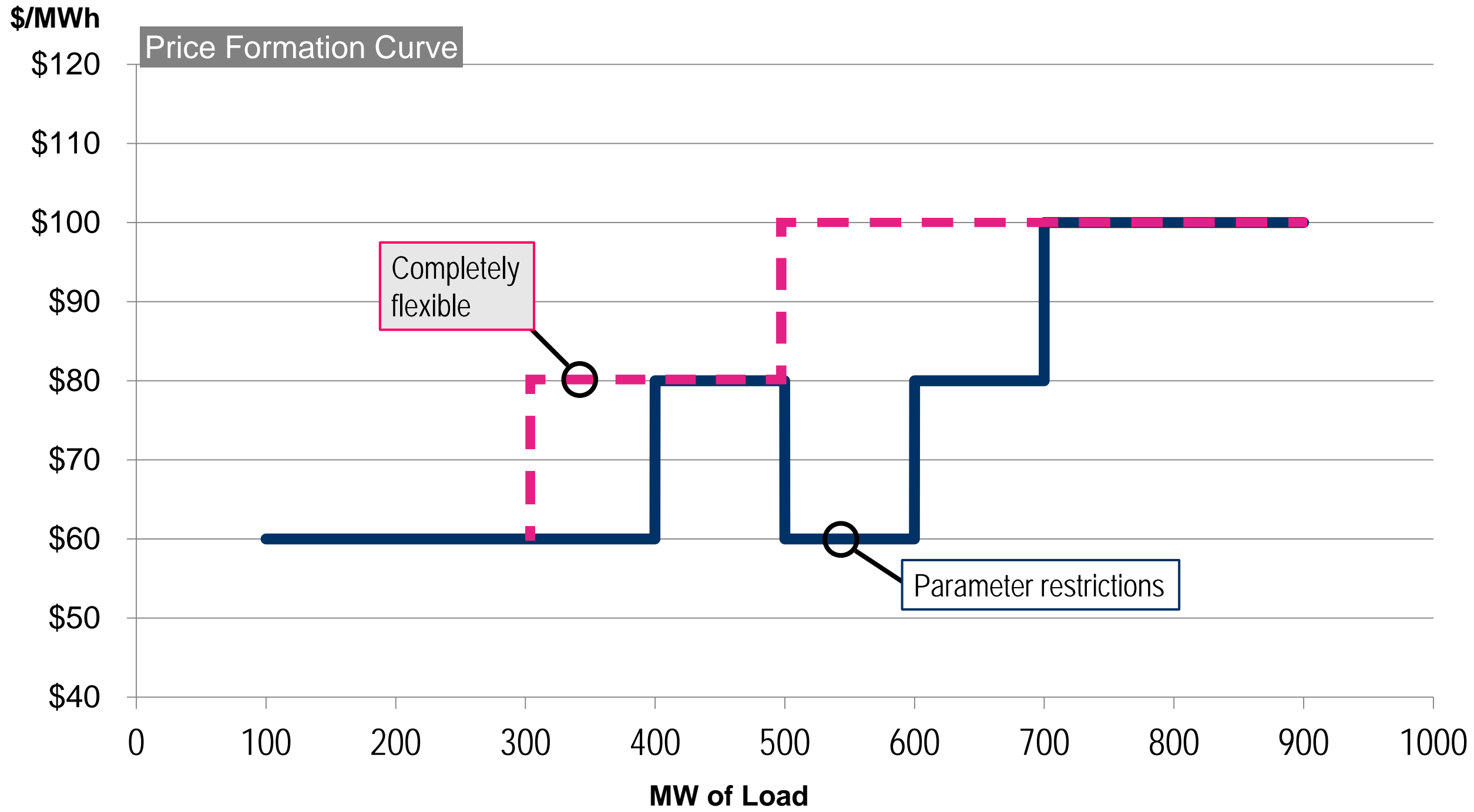
■ Available
▨ Minimum Output







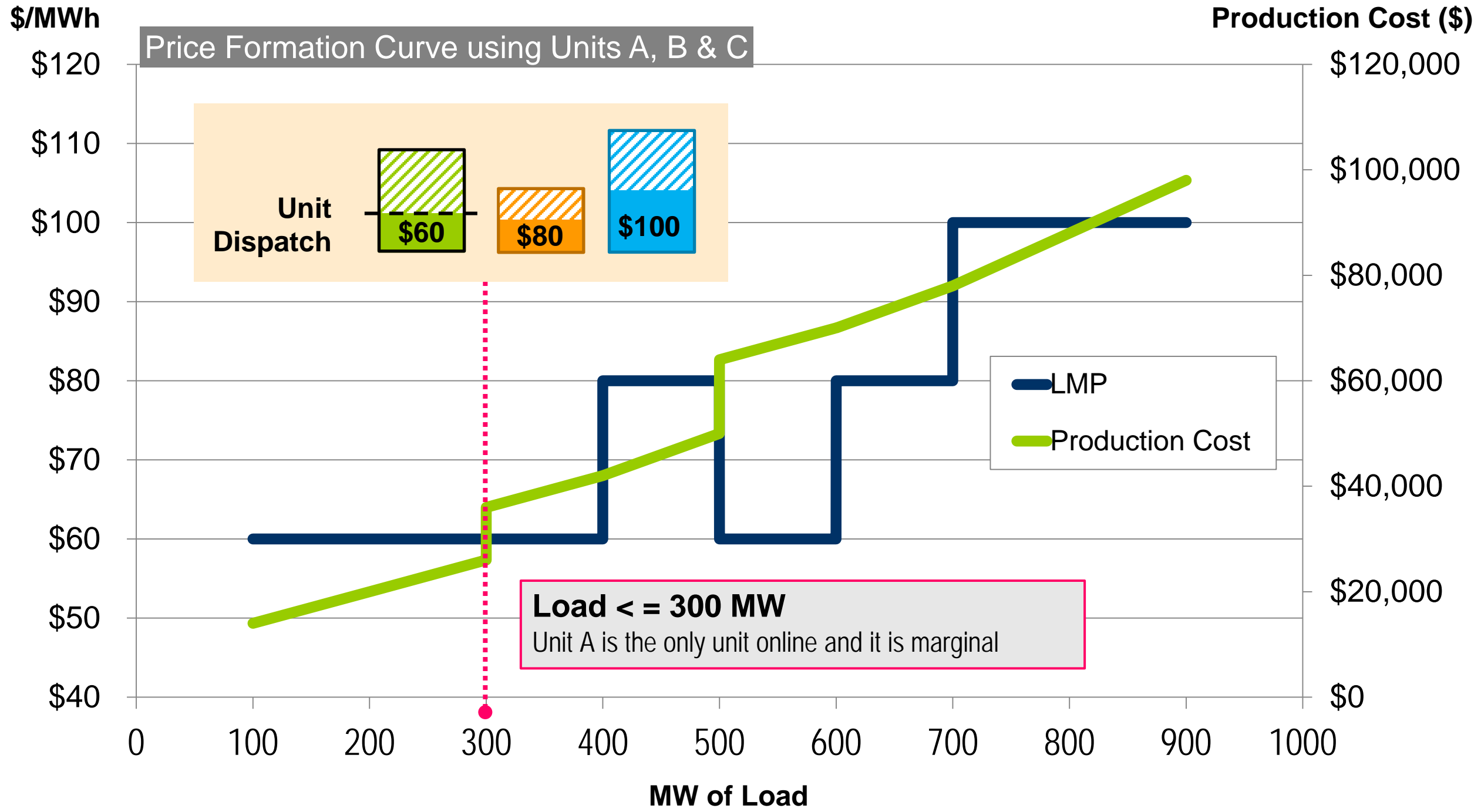


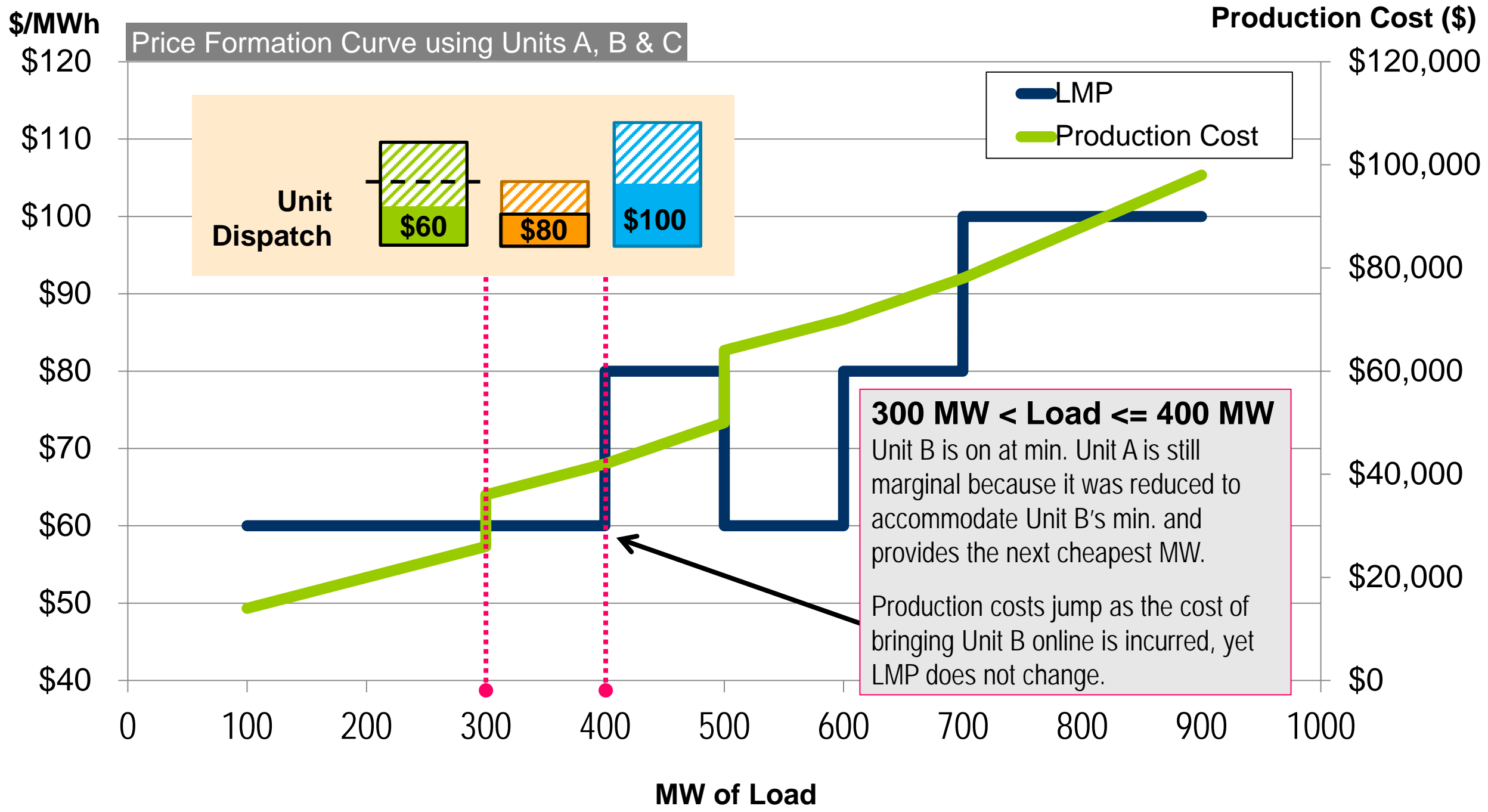


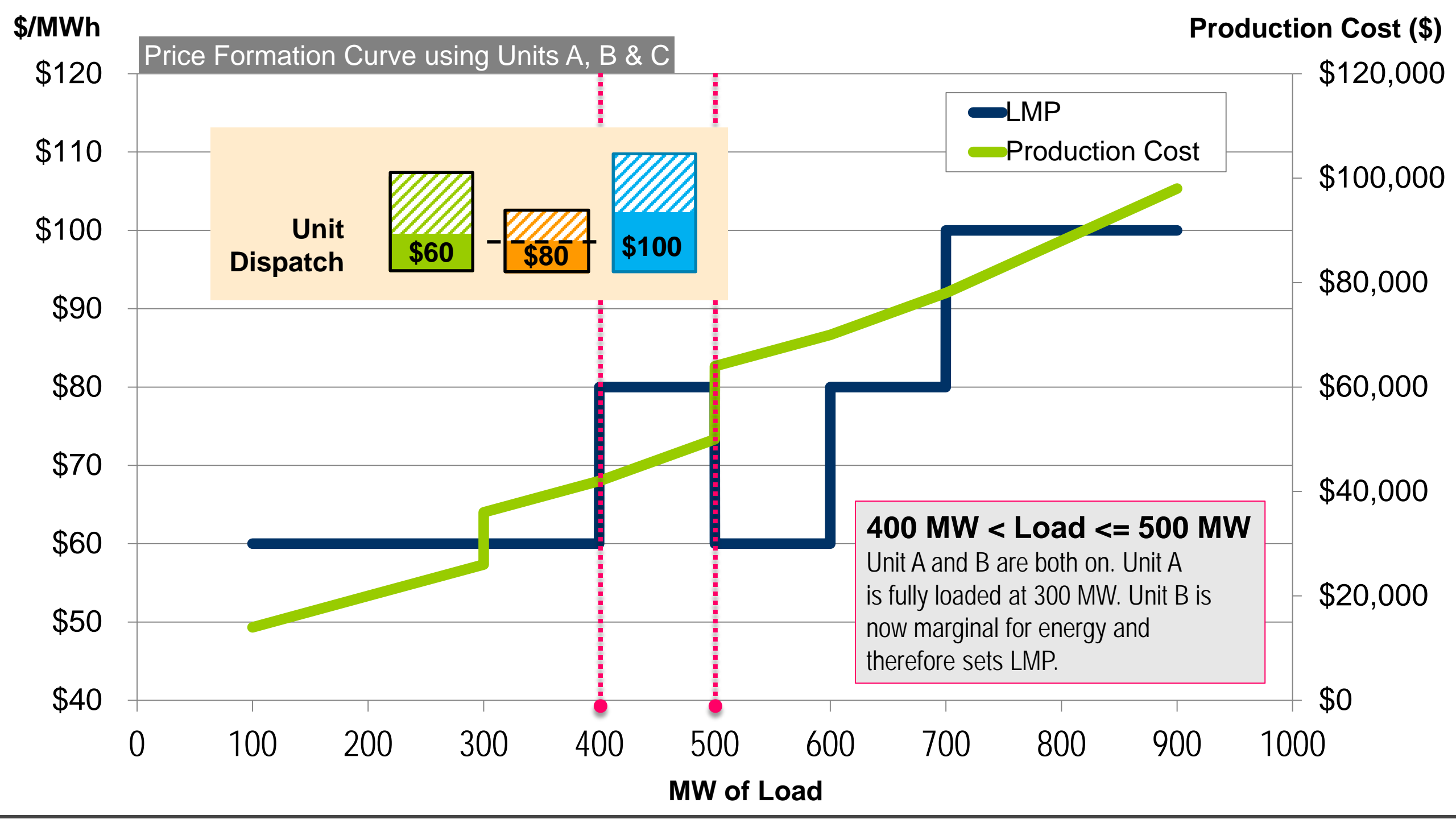
Price Formation Curve

Completely flexible

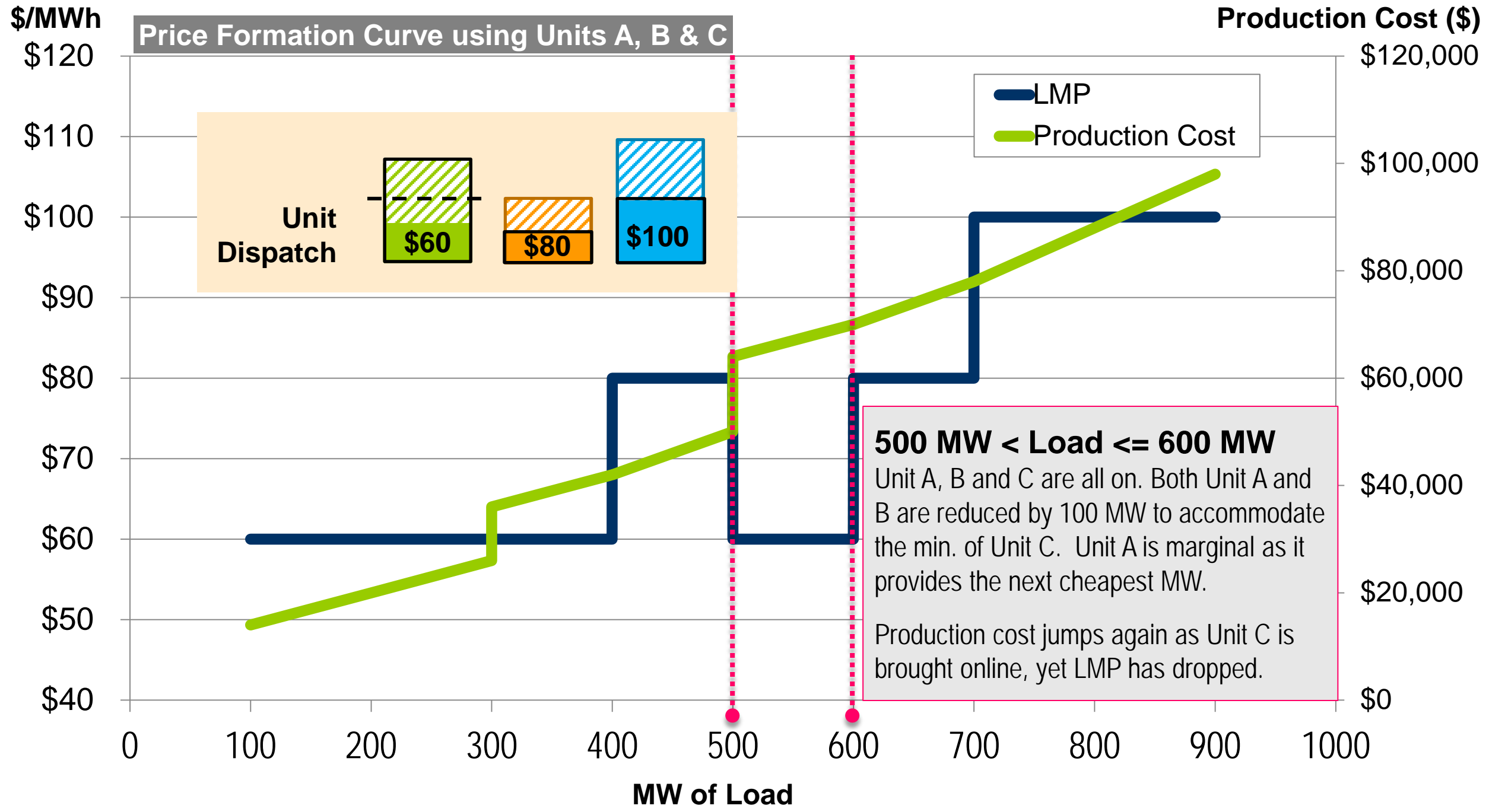
Parameter restrictions

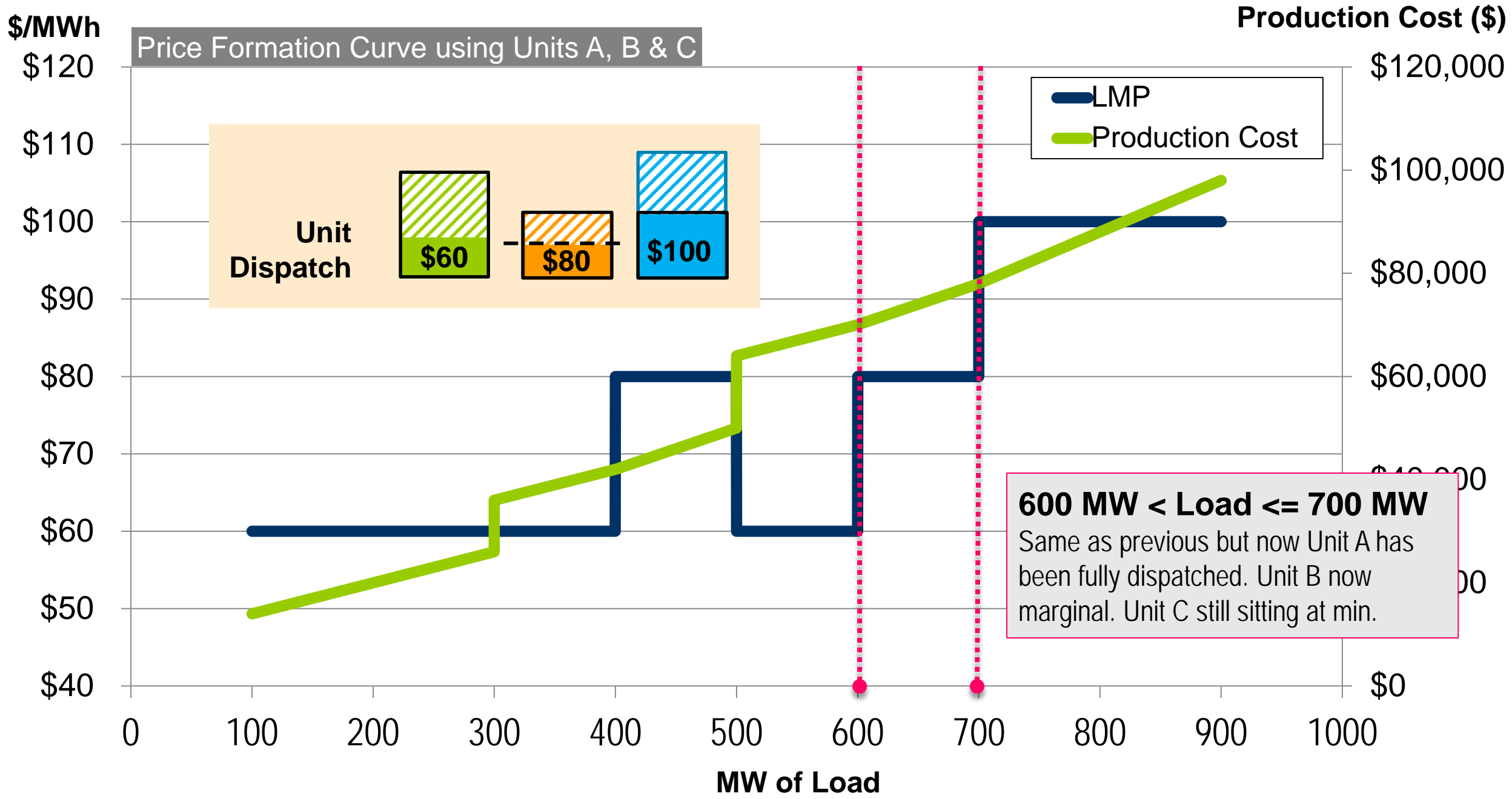




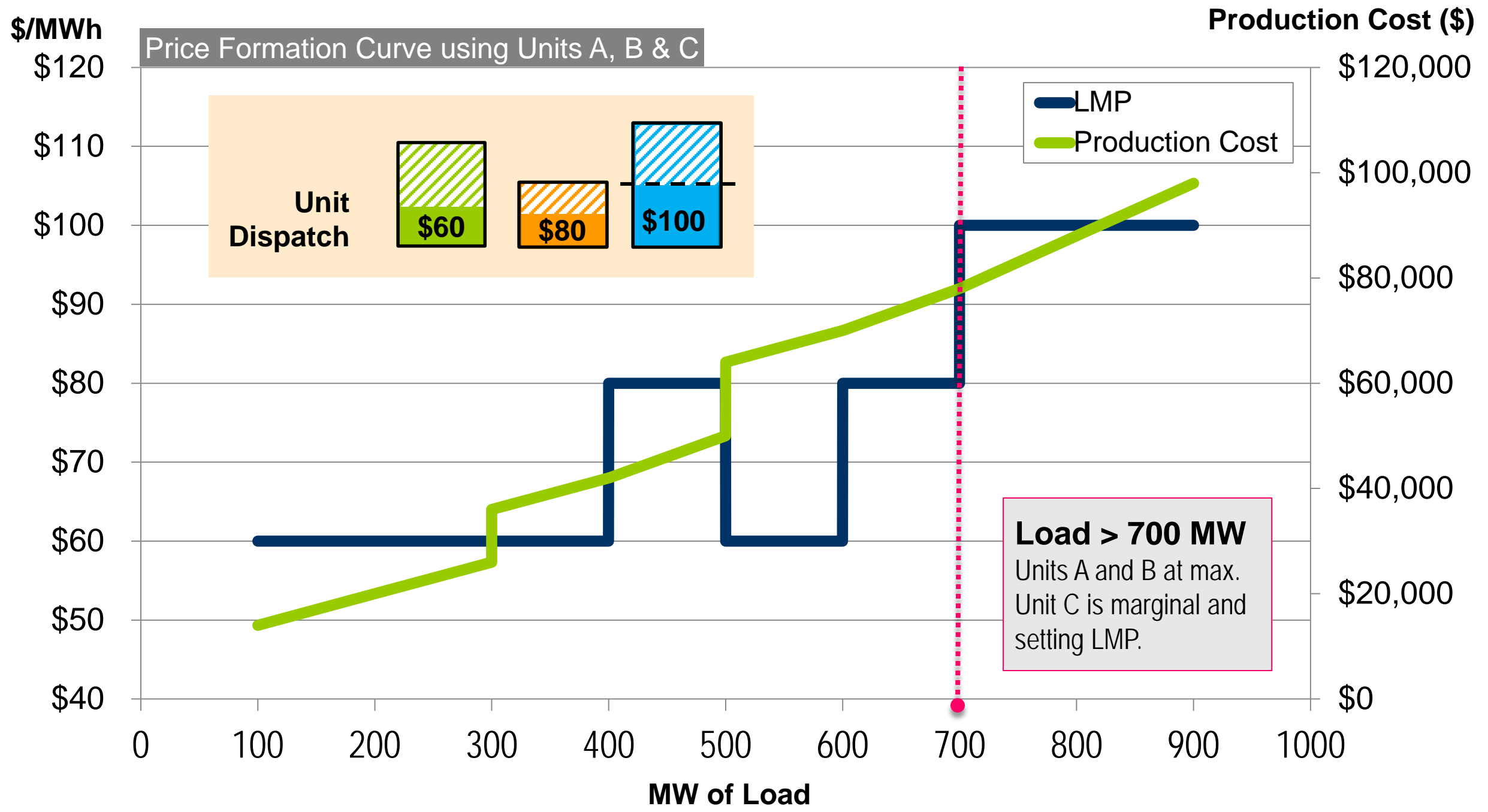


Price Formation Curve using Units A, B & C





Price Formation Curve using Units A, B & C



\$/MWh
\$120
\$110
\$100
\$90
\$80
\$70
\$60
\$50
\$40

Production Cost (\$)
\$120,000
\$100,000
\$80,000
\$60,000
\$40,000
\$20,000
\$0

Unit Dispatch

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— LMP
— Production Cost

Load > 700 MW
Units A and B at max.
Unit C is marginal and setting LMP.

LMP AND UPLIFT EXAMPLES

Set 2

Hour 1

LMP = \$35/MWh

Load =
700 MW



Units A and D are flexible

Units B and C are lumpy or
block-loaded

Minimum Runtime = 1 hour

Hour 2

LMP = \$35/MWh

Load =
700 MW



Unit D: \$35
200 MW

Unit C: \$30
200 MW

Unit B: \$25
200 MW

Unit A: \$10
200 MW

Example 5: Declining Demand

Hour 1

LMP = \$35/MWh

Load =
700 MW



Units A and D are flexible

Units B and C are lumpy or block-loaded

Minimum Runtime = 1 hour

Hour 2

LMP = \$35/MWh

Load =
500 MW



Example 5: Unit C has an Incentive to Bid Inflexibly

Hour 1

LMP = \$35/MWh

Load =
700 MW



Units A and D are flexible

Units B and C are lumpy or block-loaded

Minimum Runtime = 1 hour

Hour 2

LMP = \$35/MWh

Load =
500 MW



Unit B: \$25
200 MW

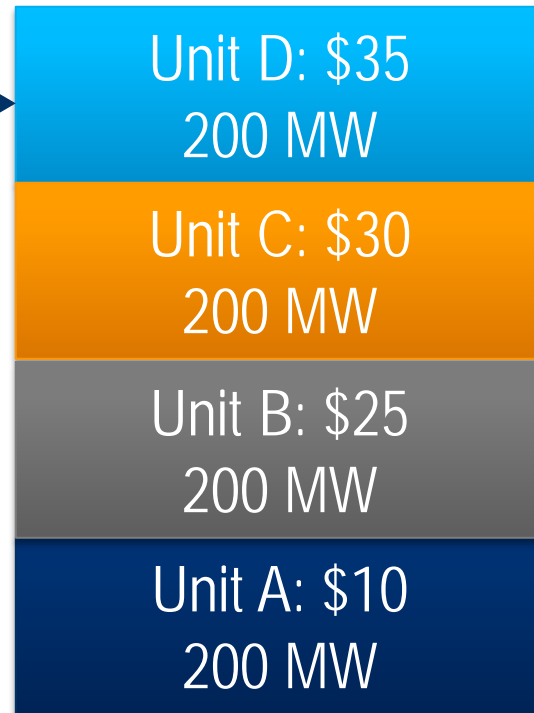
Unit C raises its Minimum Runtime to 2 hours and replaces Unit B

Example 5: Units B & C have an Incentive to Bid Inflexibly

Hour 1

LMP = \$35/MWh

Load =
700 MW



Units A and D are flexible
Units B and C are lumpy or block-loaded
Minimum Runtime = 1 hour

Hour 2

LMP = \$10/MWh
Uplift = \$4,000

Load =
500 MW



Both units B and C raise their Minimum Runtime to 2 hours and are dispatched

APPENDIX

LMP AND UPLIFT EXAMPLES

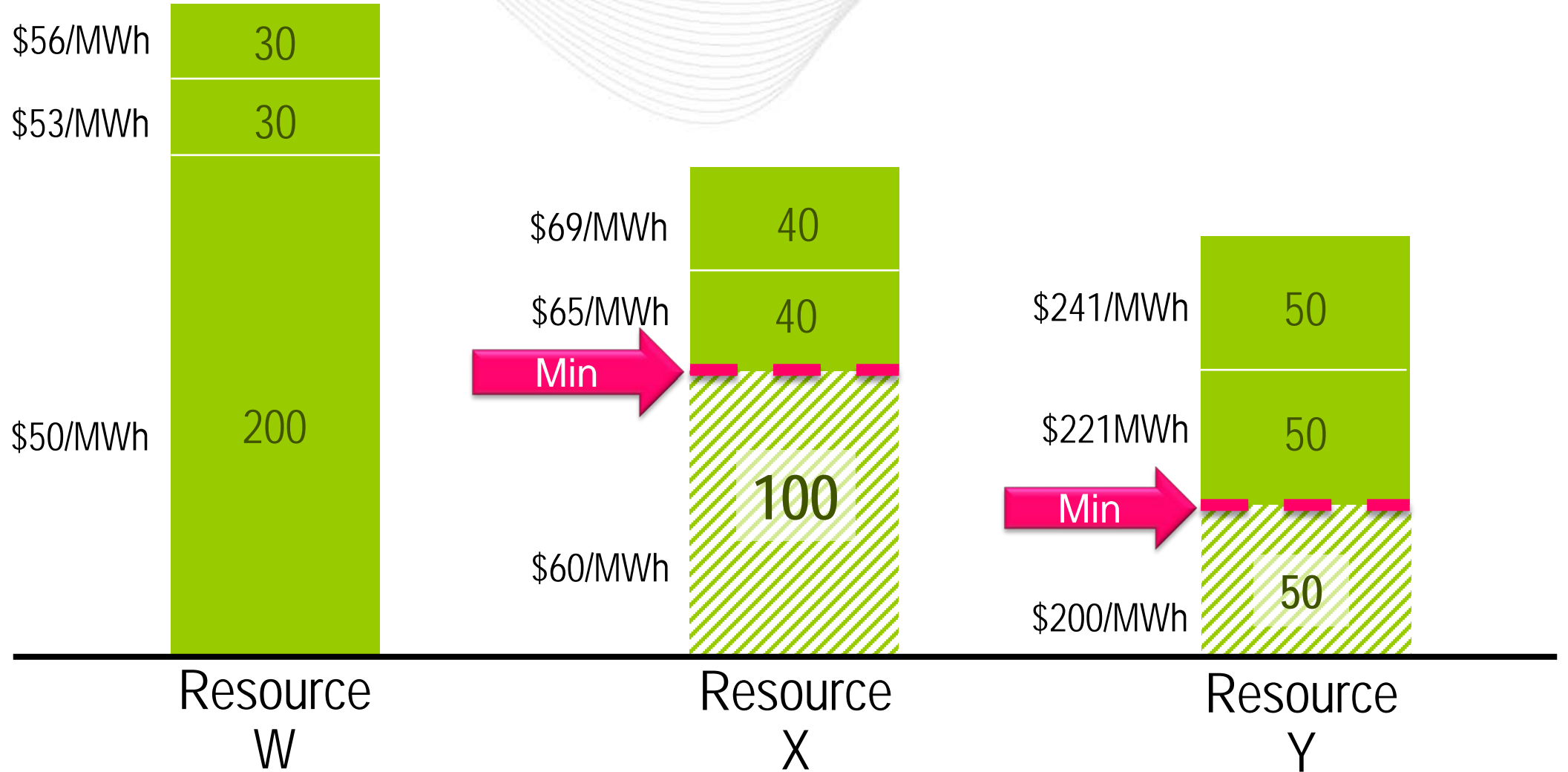
Set 3

- **Load = 480 MW**
- No imports, exports or price-sensitive demand
- Can be considered in the context of the Day-Ahead or Real-Time Market
- Objective: to determine the **least-cost commitment and dispatch** to meet the load

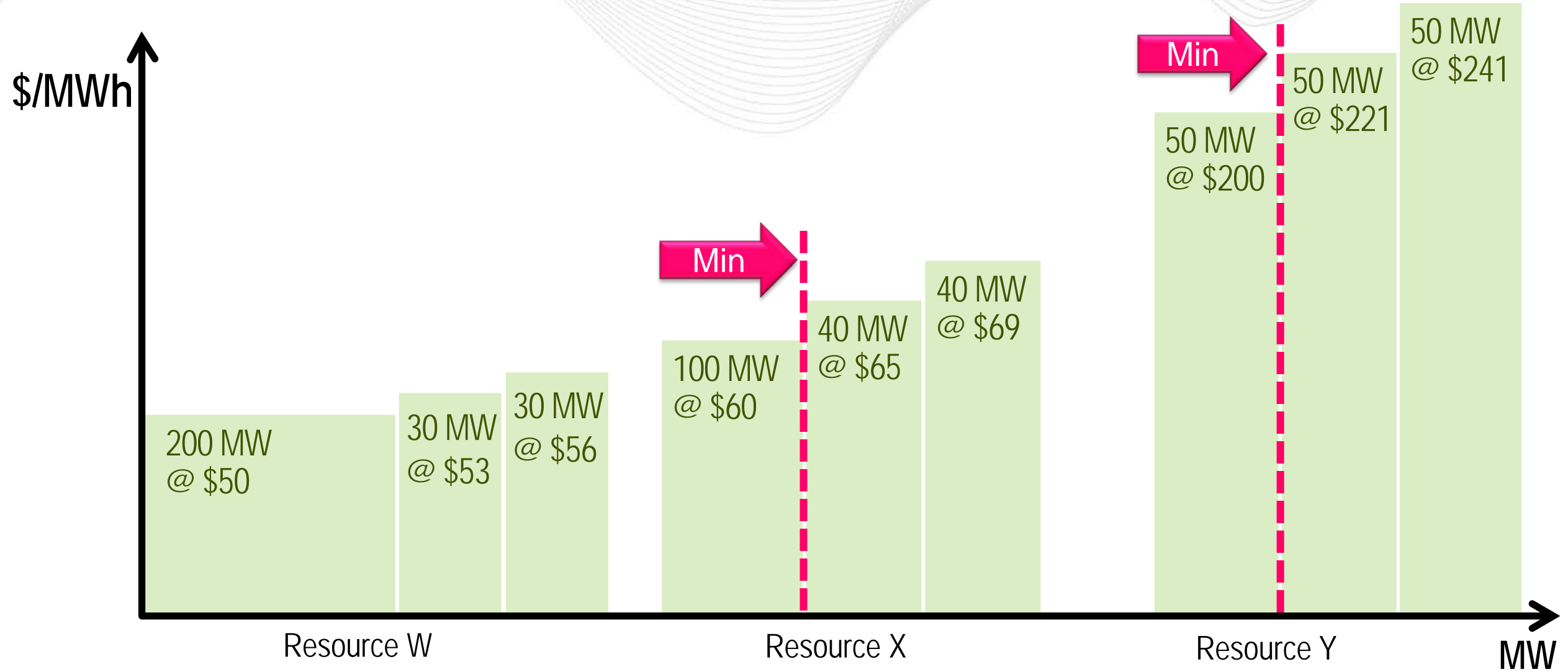
Note: The following numerical example was initially developed by ISO New England and is used with permission.

https://www.iso-ne.com/static-assets/documents/support/training/courses/energy_mkt_ancil_serv_top/price_information_technical_session_session4.pdf

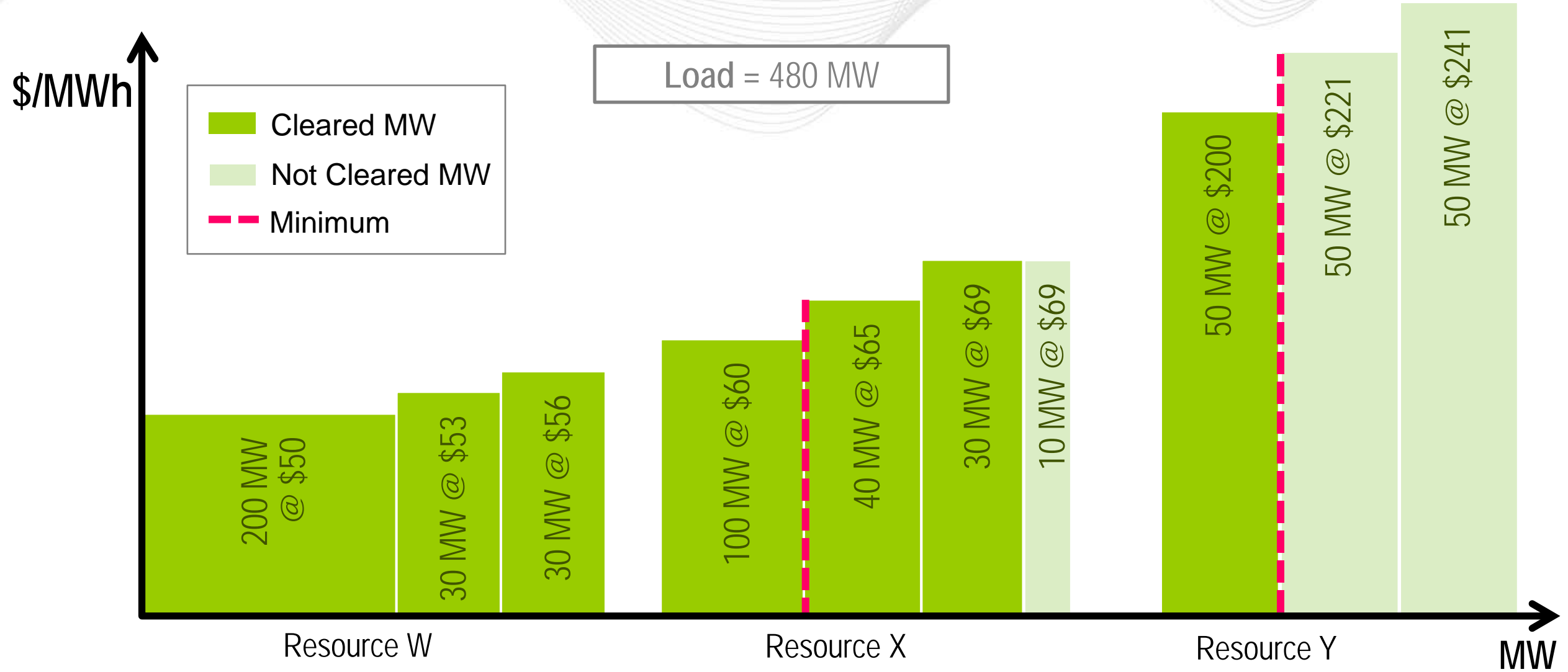
Any resource that is "committed" must run at least at its minimum.



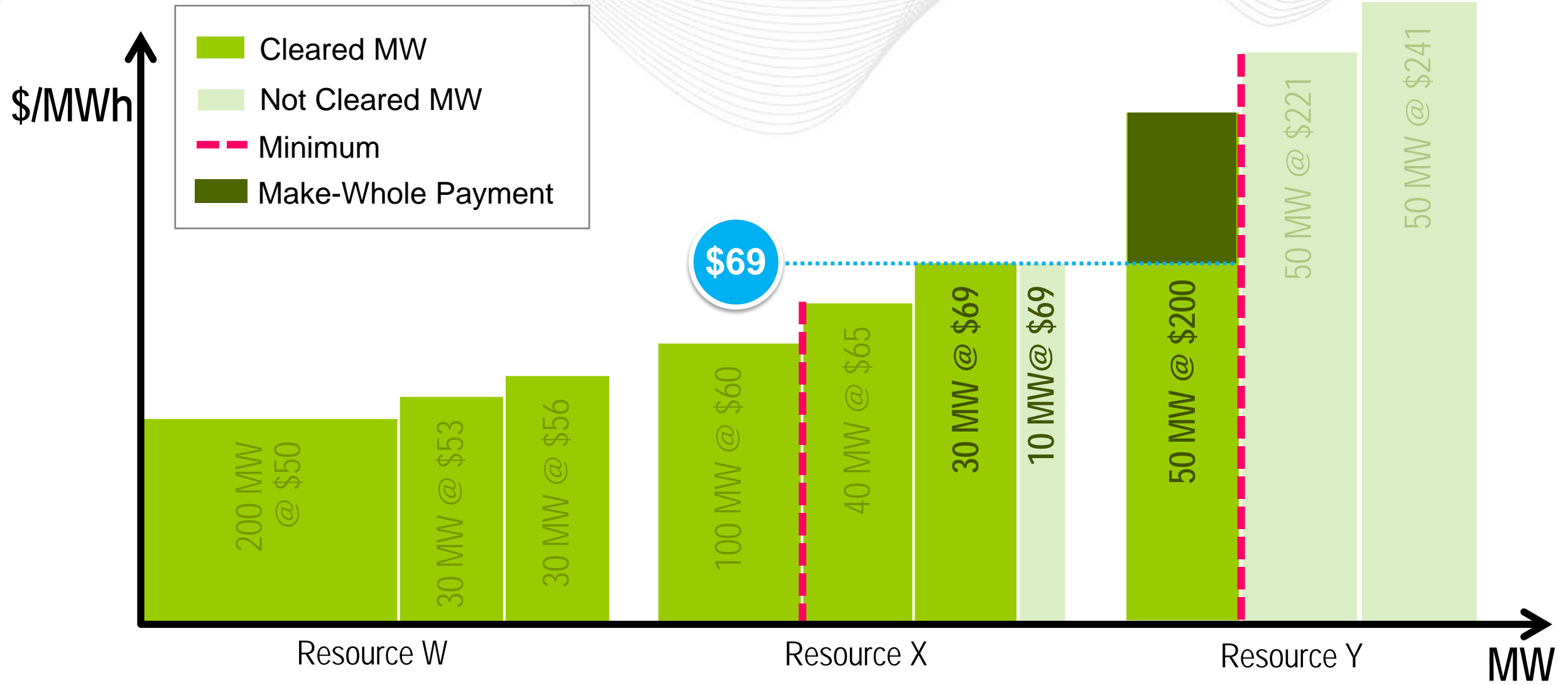
Example #1: Marginal Pricing with Minimum Generation



Example #1: What Is the Commitment and Dispatch?



Example #1: What Is the Commitment and Dispatch?



The settlement:

LMP = \$69/MWh

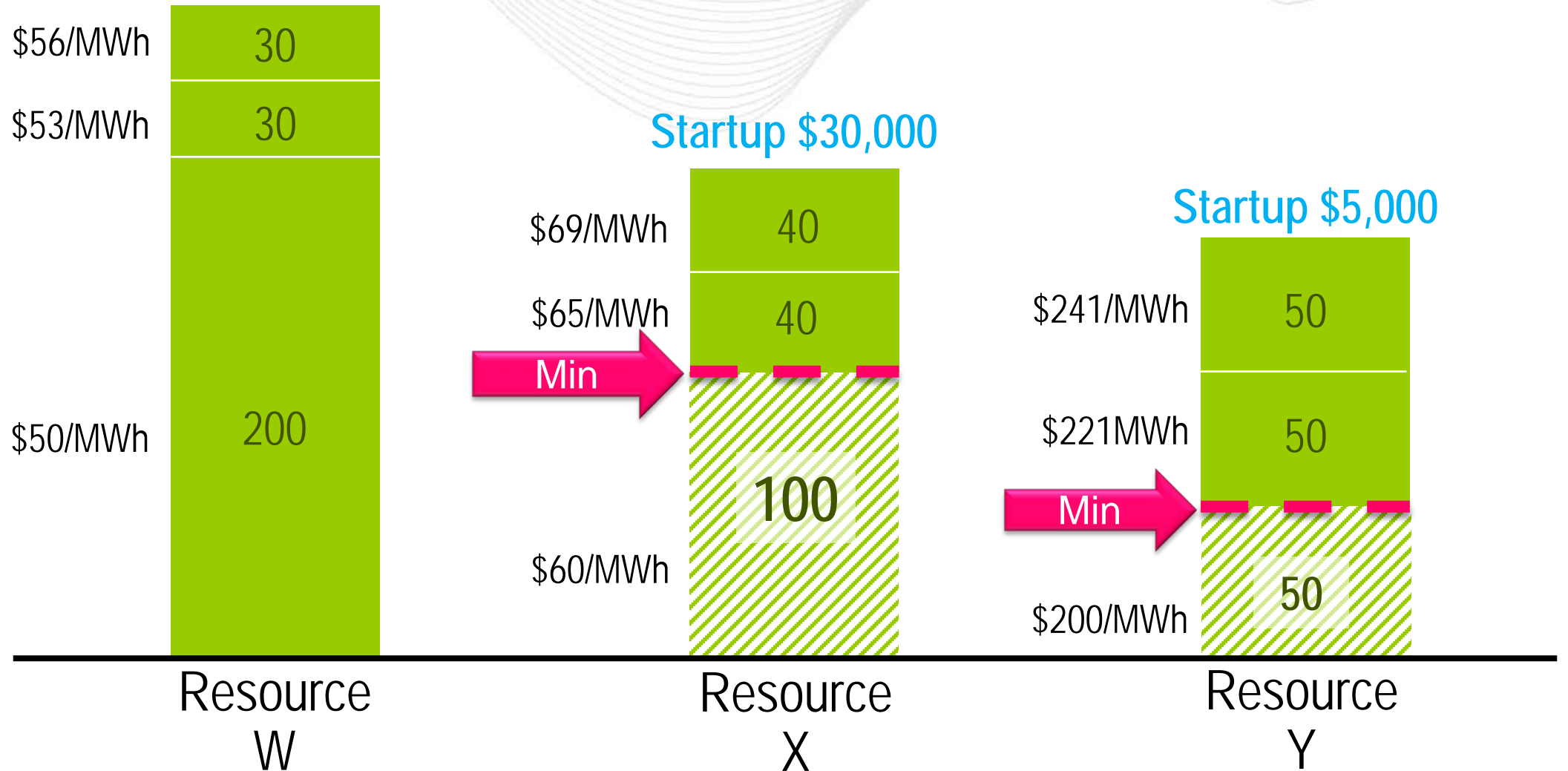
Resource	Commitment	Dispatch (MW)	Total Offer Cost (\$)	Payment (\$)	MWP (\$)
W	On	260	13,270	17,940	0
X	On	170	10,670	11,730	0
Y	On	50	10,000	3,450	6,550

Y has an incentive to deviate from the 50 MW dispatch (it would prefer 0 MW given the \$69/MWh price) without the make-whole payment.

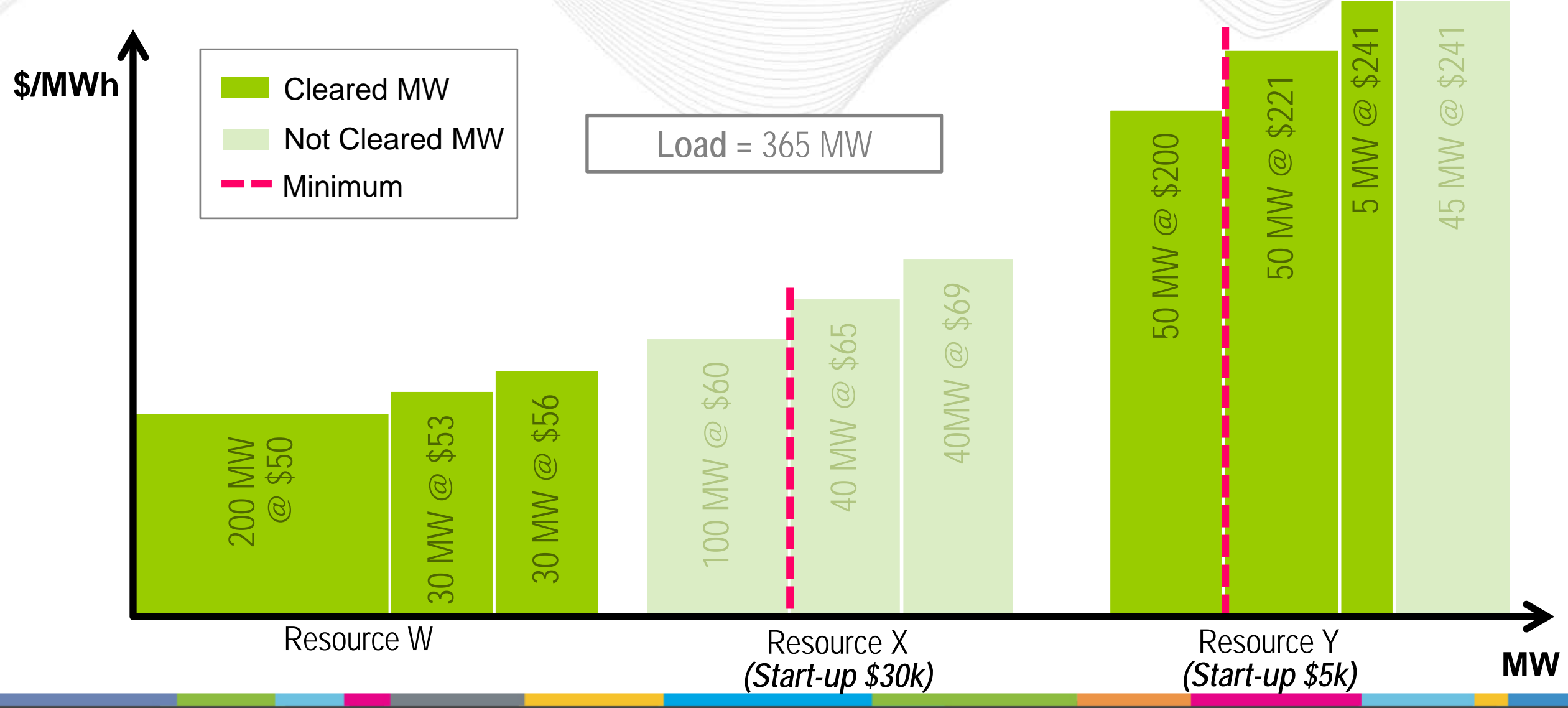
- Load = 365 MW
- **Same offer blocks** as Example #1 for each resource
- **Fixed costs (start-up) added** to Resource X and Resource Y

Example #2: Offer Blocks (MW) & Fixed Costs

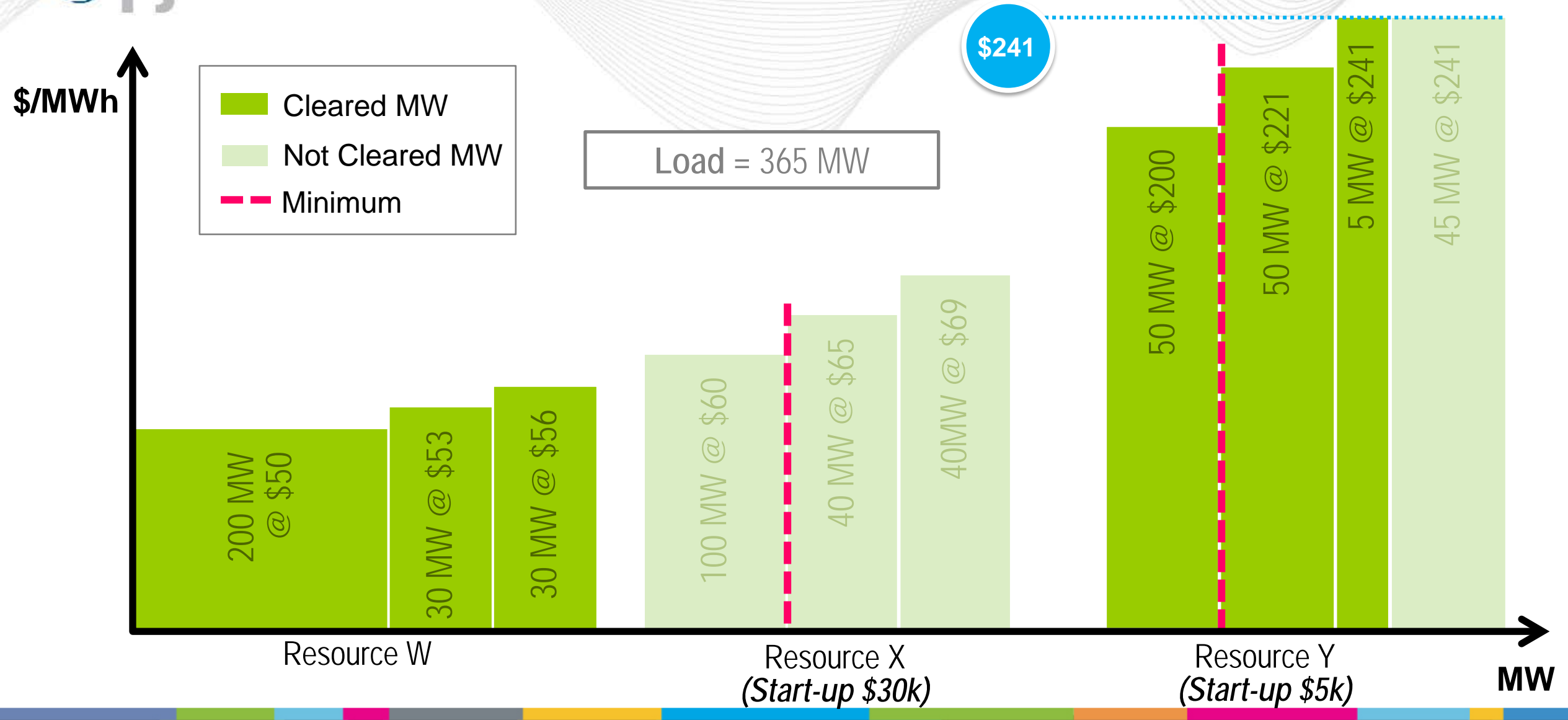
Any resource that is "committed" must run at least at its minimum



The Commitment and Dispatch: Example #2



The Commitment and Dispatch: Example #2



The **LMP** is **\$241/MWh**.

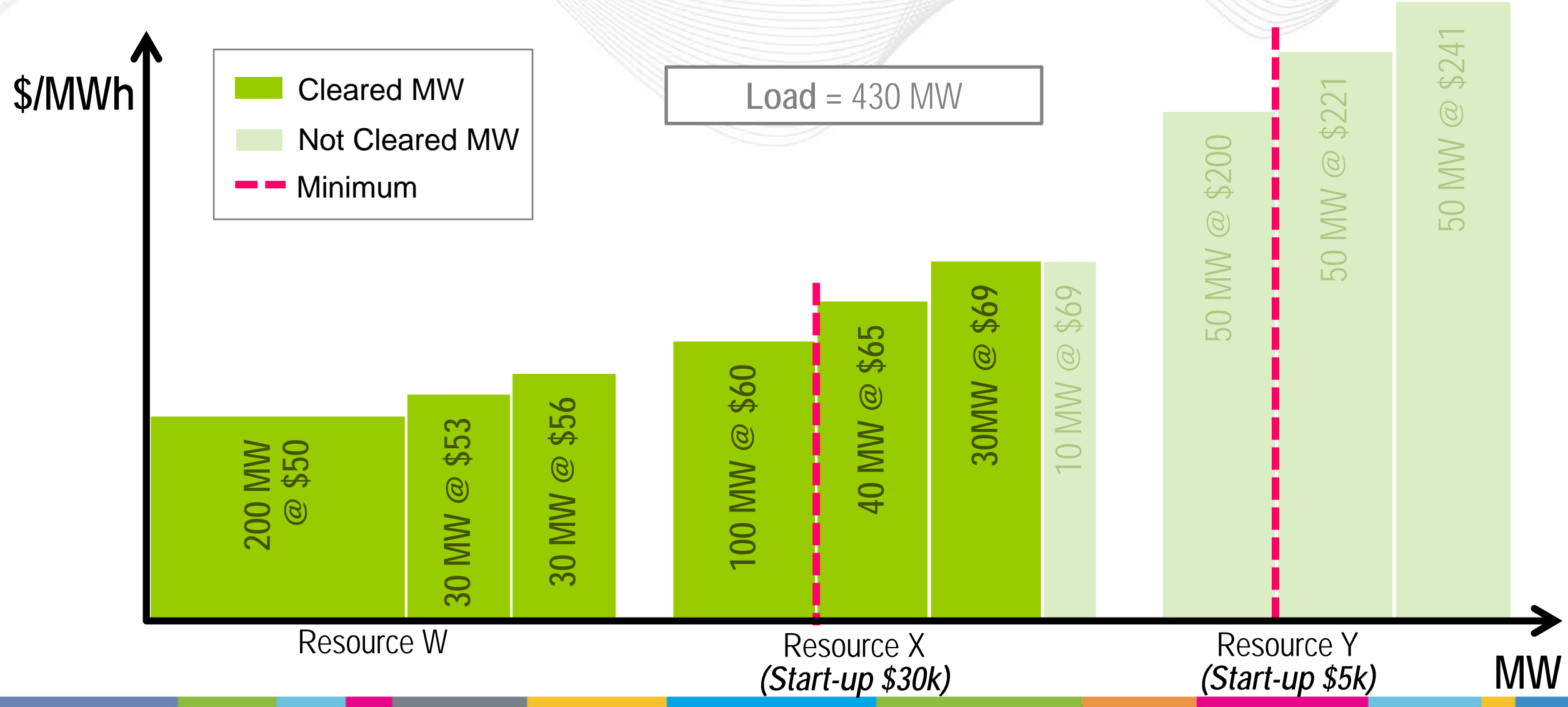
Resource	Commitment	Dispatch (MW)	Total Offer Cost (\$)	Payment (\$)	MWP (\$)	LOC (\$)
W	On	260	13,270	62,660	0	0
X	Off	0	0	0	0	2,020
Y	On	105	27,255	25,305	1,950	0

Reminder: At X's offer prices of \$60–\$69/MWh, it would want to come online at a \$241/MWh clearing pricing since it would make a profit at \$241/MWh of \$2,020. Today's markets in general do not pay this LOC to offline resources.

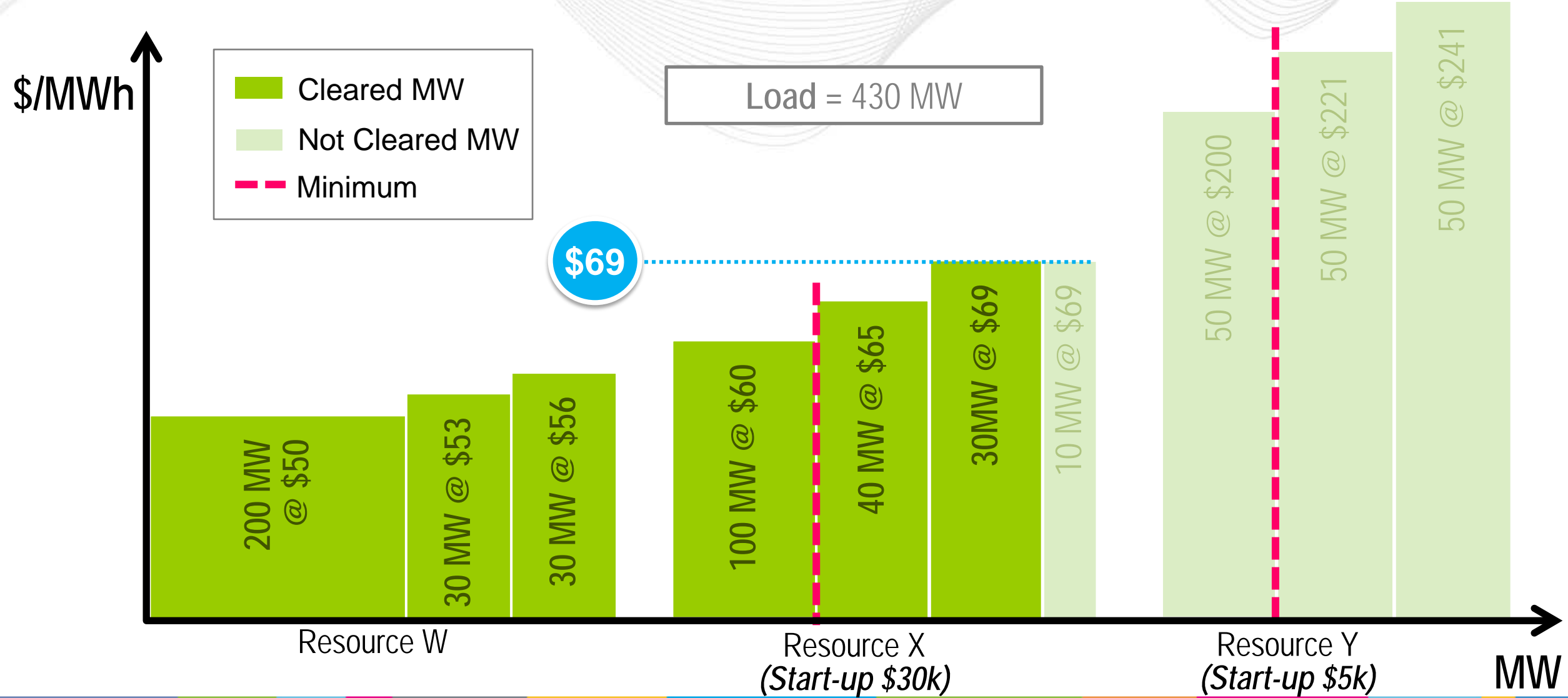
What if the Load Went Up for this Example?

- As total load rises, the total offer cost of meeting that demand rises.
- Increase load to:
 - Example 3 – Load = 430 MW
 - Example 4 – Load = 445 MW

The Commitment and Dispatch: Example #3



The Commitment and Dispatch: Example #3



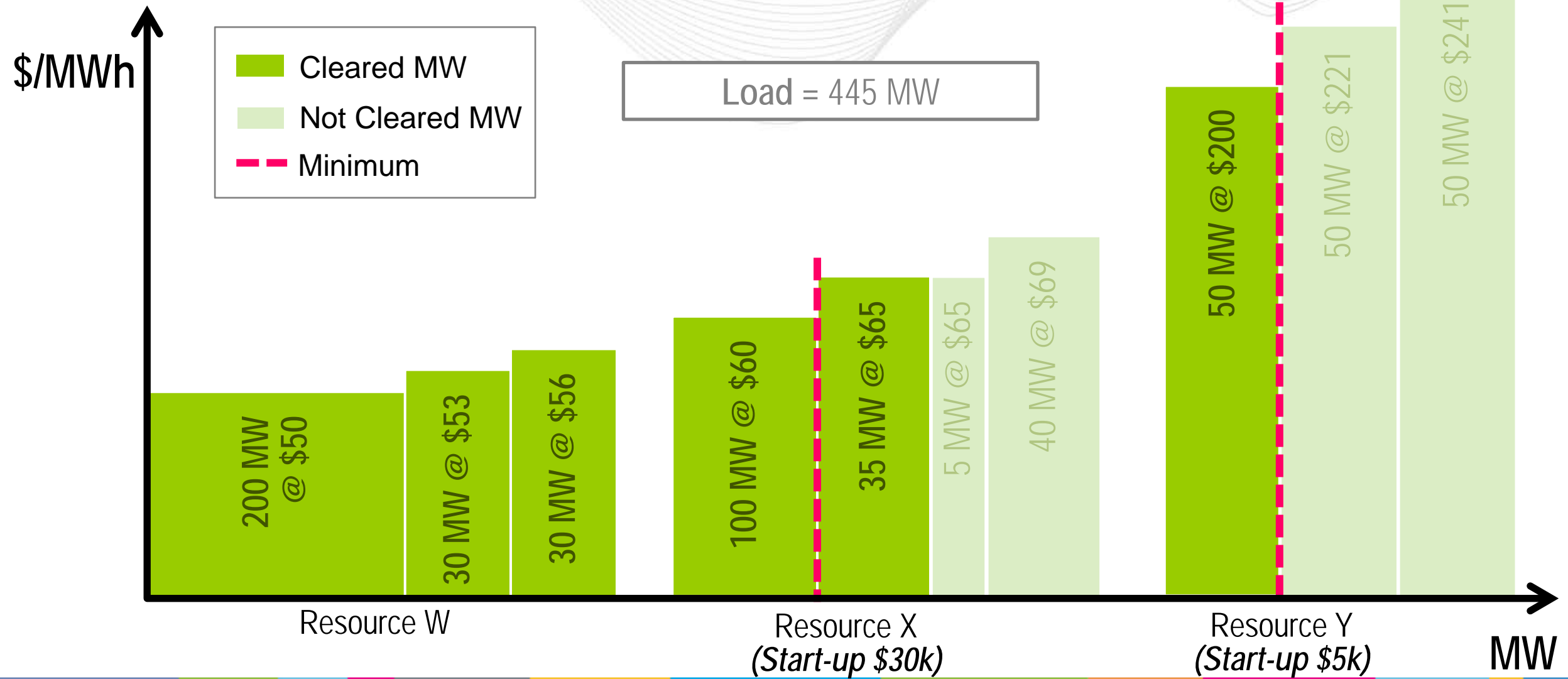


Example #3: Pricing and Settlement

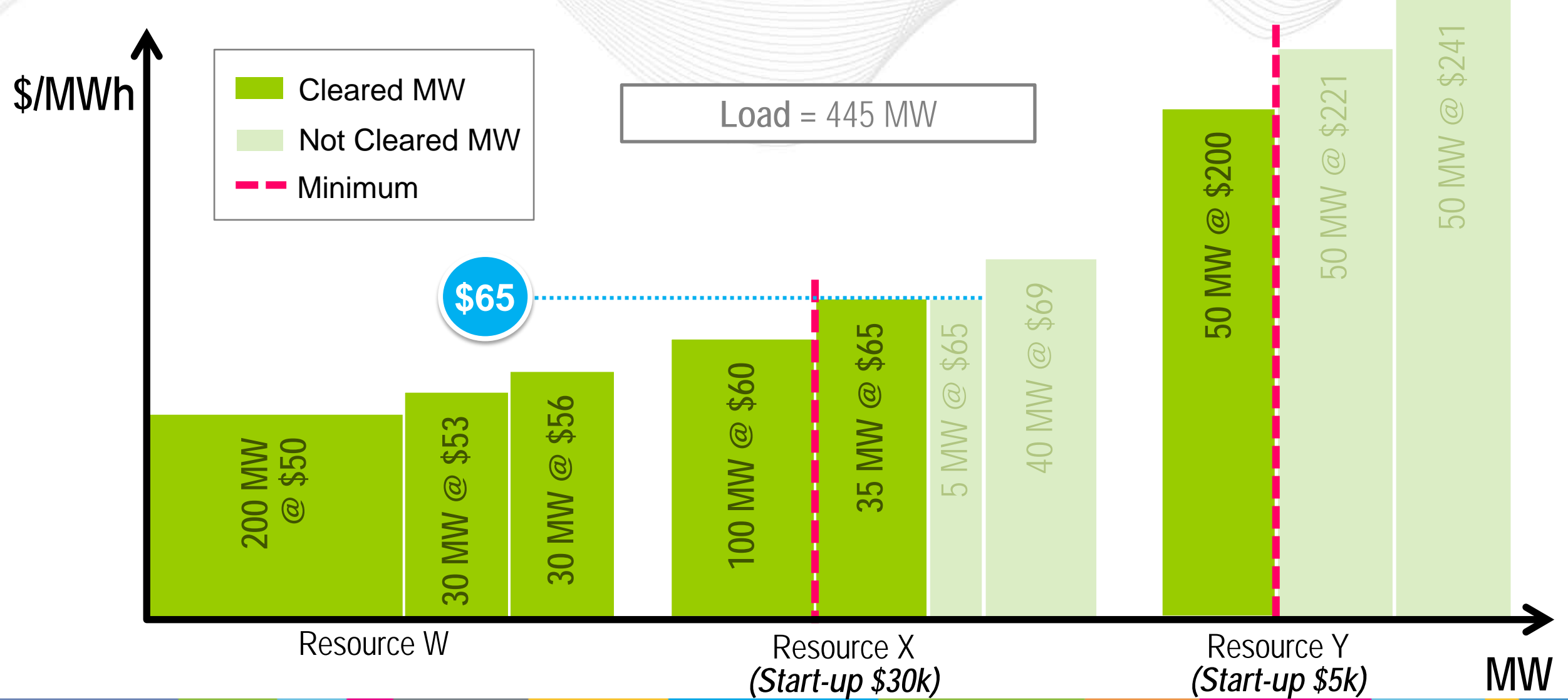
The **LMP** is **\$69/MWh**.

Resource	Commitment	Dispatch (MW)	Total Offer Cost (\$)	Payment (\$)	MWP (\$)	LOC (\$)
W	On	260	13,270	17,940	0	0
X	On	170	40,670	11,730	28,940	0
Y	Off	0	0	0	0	0

The Commitment and Dispatch: Example #4



The Commitment and Dispatch: Example #4





Example #4: Pricing and Settlement

The **LMP** is **\$65/MWh**:

Resource	Commitment	Dispatch (MW)	Total Offer Cost (\$)	Payment (\$)	MWP (\$)	LOC (\$)
W	On	260	13,270	16,900	0	0
X	On	135	38,275	8,775	29,500	0
Y	On	50	15,000	3,250	11,750	0

- In Examples 2-4, the price decreases as load increases

Load (MW)	LMP (\$/MWh)
365	241
430	69
445	65