GHG Price Formation

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Evergreen Training: Greenhouse Gas (GHG) Price Formation

- This pre-recorded training gives stakeholders an opportunity to get up-to-speed on, or dive more deeply into, price formation with GHG.

- The material in this training is intended to be a durable representation of the fundamentals of GHG market design in ISO markets.

- The PDF of this full presentation can be found on the "Greenhouse gas coordination working group" stakeholder initiative page on the ISO website.

Hold for Housekeeping slide

- This is chapter 1 of 4. The other 3 chapters are available under the “GHG Coordination Evergreen Trainings” playlist on the California ISO’s YouTube channel.

- We welcome your feedback! Please send any questions, comments, or feedback on this training to ISOStakeholderAffairs@caiso.com with “GHG Price Formation” in the subject line
  - The ISO will collect the questions and post responses in the form of an FAQ to the initiative webpage

This training is intended to build your understanding of…

- The role of GHG price formation in market GHG policy today

- The basic mechanics of price formation with GHG, including:
  - How GHG is reflected in the market
  - How the market determines what resources to attribute to a GHG regulation area
  - How prices are determined, what those prices mean, and how costs associated with GHG are allocated to market participants

- The relationship between GHG and price formation principles, the market design, and the data that comes out of the market

Overview of GHG Price Formation Evergreen Training

- Chapter 1: Background and Context
- Chapter 2: Optimization Basics
- Chapter 3: Optimizing with GHG
- Chapter 4: Examples of Price Formation with GHG

Chapter 1

BACKGROUND AND CONTEXT

Chapter 1: Background and Context

- The next three chapters show *how* GHG price formation works, so this chapter will focus on *why:*
  - Why reflect state GHG policy in the market?
  - Why might GHG show up in market results the way that it does?

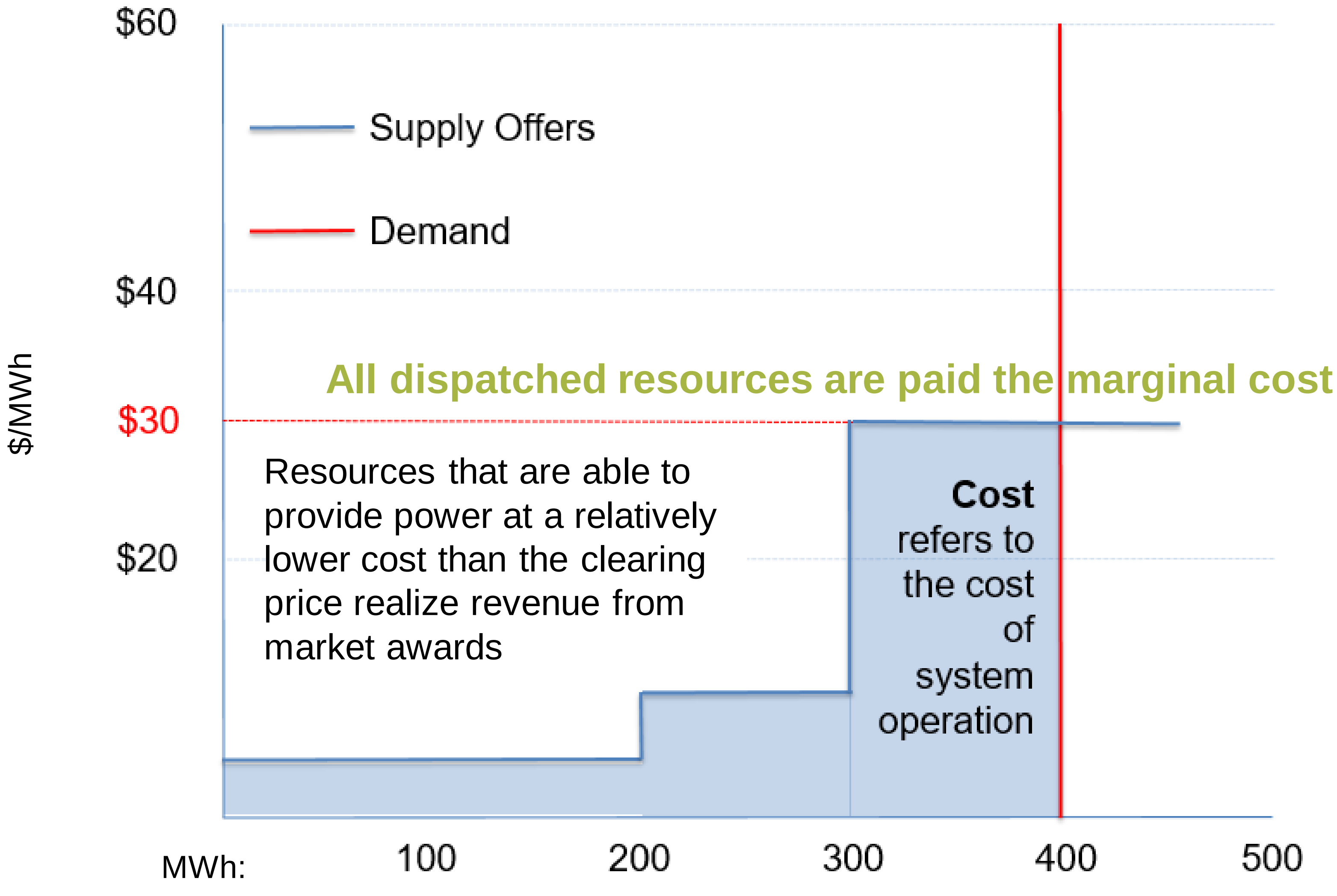
- This chapter defines some fundamental principles and concepts. Subsequent chapters will illustrate and iterate on these same ideas in different ways.

Common Price Formation Principles

- Prices should provide a sufficient incentive for resources to follow their dispatch instructions

- Everyone is paid the same price:
  - The marginal resource setting the price makes $0 profit, and is indifferent to dispatching capacity across its operational range
  - Infra-marginal resources make a profit. Resources that are able to dispatch at a relatively lower cost than the marginal resource should have an incentive to dispatch their full capacity.

Cost savings and efficiency come from least-cost dispatch and price formation



A regional market provides cost savings and efficiency by dispatching all resources as a single market

- LSEs and BAAs bring resources to the table, and the market determines
  - How to meet load at least-cost, taking into account available resources and constraints
  - How to set prices that would incentivize least-cost dispatch

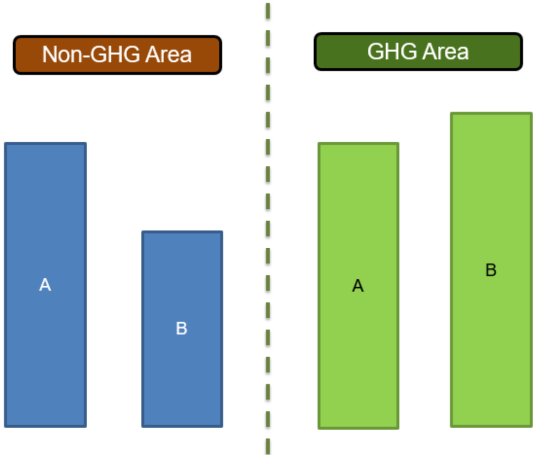
- What is dispatched and accounted for through the market may be different in any given real-time interval than what an LSE brings to the table

Integrating GHG pricing into the market

- A GHG pricing policy, like a cap-and-trade, determines a price for emissions that can impact the marginal energy cost of resources subject to compliance

- Different jurisdictional preferences for how GHG costs show up in the market has implications for dispatch and efficiency. Considering the same set of resources:
  - a "least-cost" solution may look different to different states
  - the relative value of one resource to another may look different to different states

A jurisdiction without a GHG price would view resource B as relatively less expensive than A



Resource A is a non-emitting resource
Resource B is an emitting resource

A jurisdiction with GHG price regulation would view resource A as relatively less expensive than B

Principles of GHG Market Design for EDAM

Objective: Account for GHG costs of EDAM transfers equitably, consistent with state policies of different participating entities.

The GHG framework should strive to meet the following principles:

1. To the maximum extent possible, market design should fairly reflect and be consistent with state policy objectives.
2. Jurisdictions that have not adopted a GHG or renewable procurement policy should not be improperly affected, directly or indirectly, by policies adopted by other jurisdictions.
3. The entity responsible for the output of a resource, as defined by a jurisdiction's policy, should receive the full greenhouse gas or renewable benefit and bear the full greenhouse gas cost of that resource.
4. The market design should allocate costs and benefits consistent with the applicable (i.e., state) greenhouse gas regulation policies.
5. Renewable and non-emitting resources outside of jurisdictions with greenhouse gas policies should not be unfairly disadvantaged compared to renewable and non-emitting resources inside jurisdictions with greenhouse gas programs.

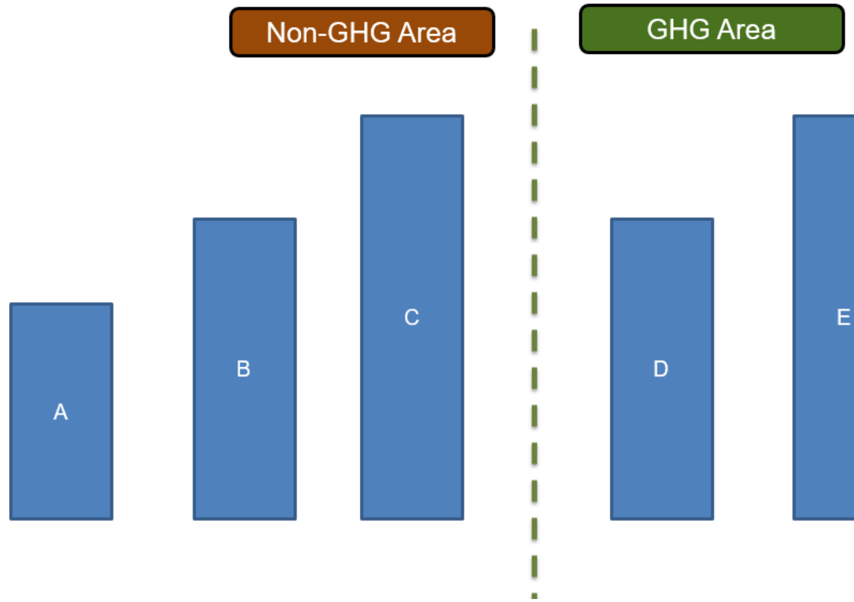
The ISO and stakeholders have worked to asses and evolve the market design to support diverse, regional GHG policy goals.

GHG price formation is just one element of broader suite of GHG market design policies that embodies these principles through different objectives.

A fundamental component of reflecting GHG pricing policies in the market, GHG price formation should be consistent with the principles described here.

GHG price formation accounts for different GHG preferences

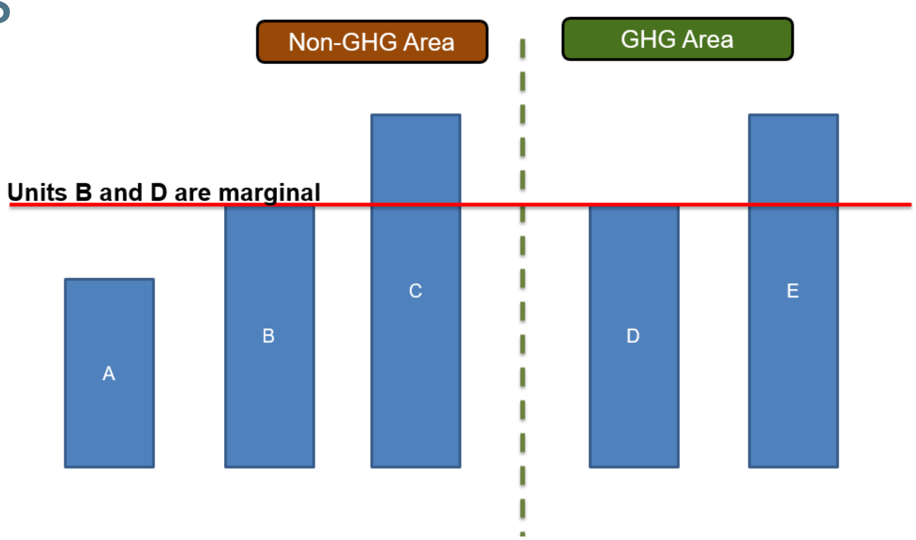
- In this conceptual example, resources A, B, C, D, and E submit energy offers indicated by the resource's height
- **A, B, and C** are located in the non-GHG area and do not account for GHG in their energy offers
- **D and E** are located in the GHG area and account for GHG in their energy offers



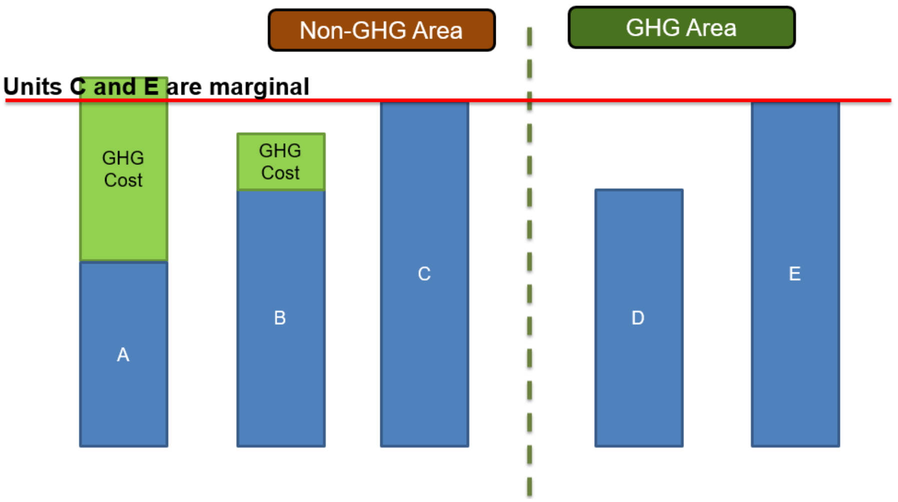
➢ Assume that in order to meet total demand from both areas, the market only needs to dispatch two of these resources and a third will set the marginal price.

Different jurisdictional preferences may result in different costs and prices

- **Units B and D are marginal** when the market considers the energy offers bid by resources

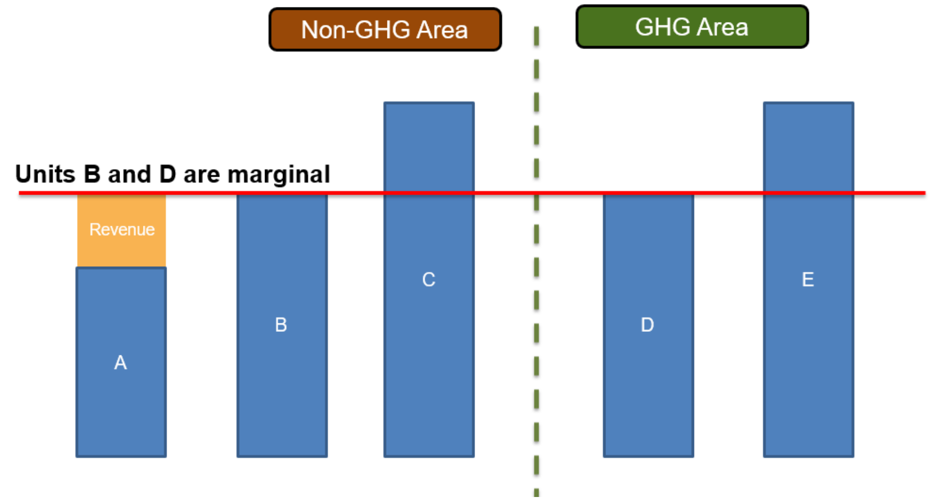


- **Units C and D are marginal** when the market considers energy offers that include the cost of compliance with GHG regulation

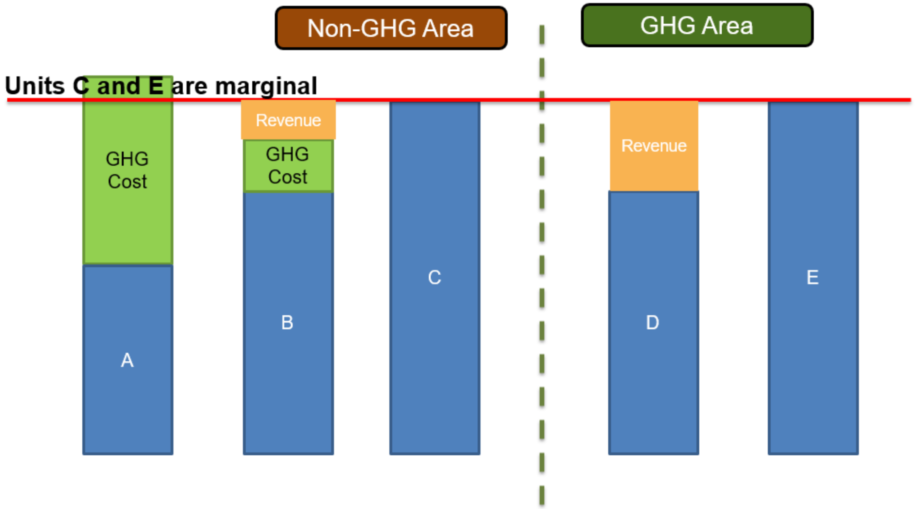


Different jurisdictional preferences may result in different costs and prices

- **Unit A is relatively less expensive** and would receive revenue from a market award based on energy costs only.



- **Units B and D are relatively less expensive.** Unit D would receive more revenue than Unit B from a market award based on energy and GHG compliance.



Objectives of Price Formation

- Prices send the right signal to resources to follow their dispatch instructions

- The energy component of market clearing prices (LMPs) reflects the incremental energy cost to the system of serving the next increment of load.

- Revenue funded through prices should
  - Cover the energy cost of resources economic to serve load
  - Provides a profit for infra-marginal resources, signaling those resources' relative cost savings to the system

Objectives of GHG Price Formation

- When considering resources in the non-GHG area for transfer into the GHG area, the GHG component of the LMP should reflect the incremental cost to the system of serving GHG area load instead of non-GHG area load.

- Additional revenue from the GHG area should:
  - Cover all compliance costs of those resources
  - Cover energy costs in excess of the price being paid by the non-GHG area of resources only economic to serve the GHG area
  - Generate additional revenue for resources that provide a relative cost savings for the GHG area

In chapter 4, we'll go through several numerical examples and check to see if these objectives are met.

GHG in market results

- The market produces a metric, the marginal cost of GHG, as a result of the market optimization. This facilitates efficient dispatch and settlement.
- States with GHG pricing policies have mechanisms to determine the cost of GHG compliance in their jurisdiction.
- The ISO and Department of Market Monitoring (DMM) publish data on market performance metrics, including GHG emissions costs and revenues

Key Concept: The marginal cost of GHG (MC-GHG)

- In the context of GHG market design, the marginal cost of GHG (MC-GHG), supports a narrow use-case specific to the market's optimization and settlement process

- A component of locational marginal prices (LMPs), the MC-GHG generates revenue funded by load in the GHG area which is used to cover costs outside the GHG area when the least-cost solution for the GHG and non-GHG areas diverge.

- In other words, the MC-GHG is the shadow price of serving the GHG area instead of the non-GHG area

Key Concept: GHG Revenue

- **GHG revenue** associated with the MC-GHG is payed for by load in the GHG area.

- GHG revenue is payed to resources in the non-GHG area to cover compliance and energy in excess of non-GHG area prices.

In chapter 4, we'll show how GHG revenue is calculated, funded, and payed to resources in the non-GHG area

The marginal cost of GHG (MC-GHG)

- When the GHG area is net exporting, like during solar hours, the least-cost solution for both the GHG and non-GHG areas is the same

EIM Green House Gas (GHG) Shadow Prices

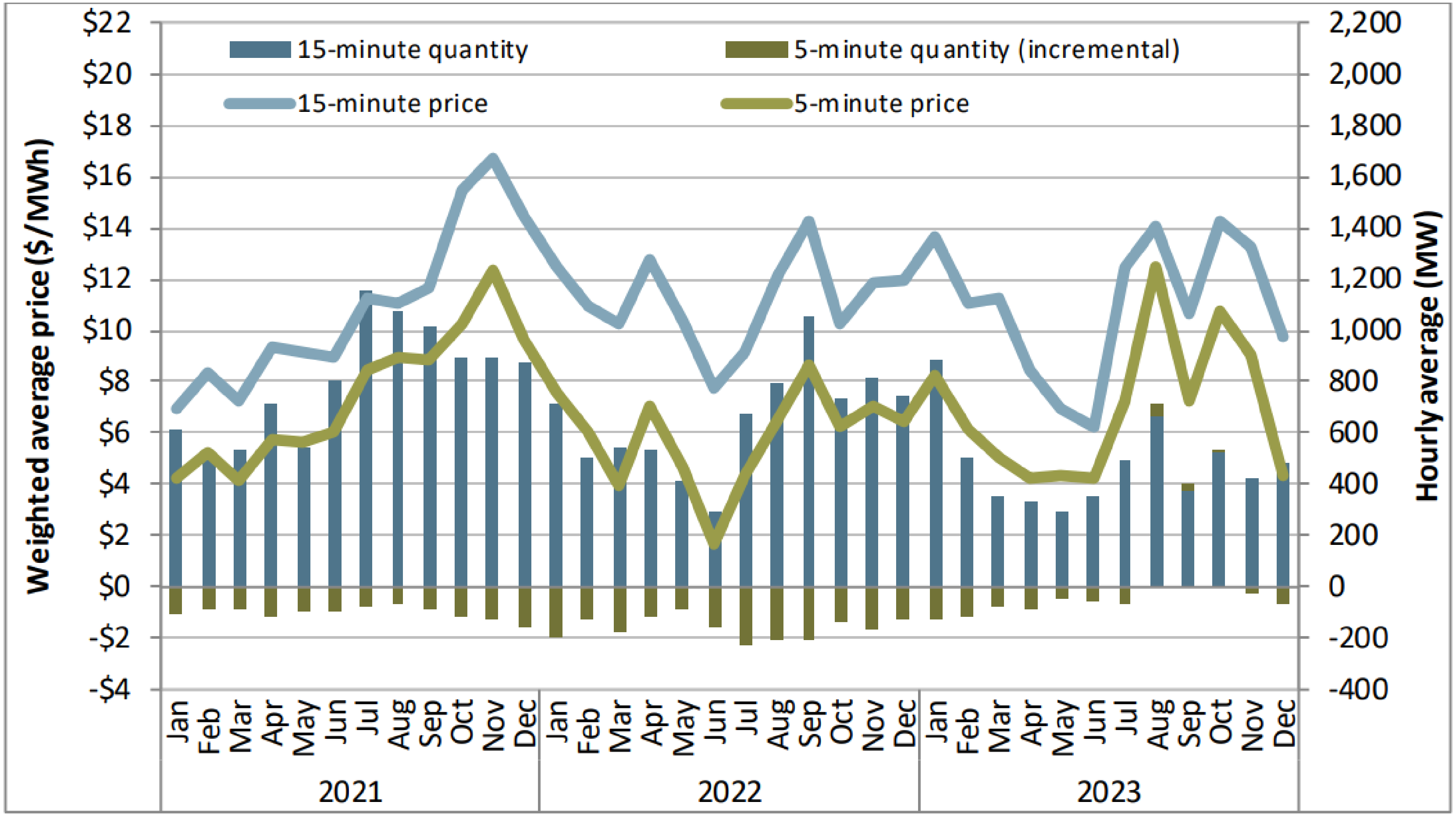
1 - 12 of ???

Market	Opr Date	Opr Interval	HE01	HE02	HE03	HE04	HE05	HE06	HE07	HE08	HE09	HE10	HE11	HE12
RTD	06/05/2024	1	-15.26	-15.26	-13.80	-14.91	-13.00	-13.00	-16.84	-15.46	-4.09	0.00	0.00	0.00
RTD	06/05/2024	2	-16.20	-15.97	-13.46	-15.12	-13.80	-13.00	-16.88	-15.46	-6.41	0.00	0.00	0.00
RTD	06/05/2024	3	-16.26	-15.97	-13.80	-14.74	-14.41	-13.85	-17.09	-15.46	-2.89	0.00	0.00	0.00
RTD	06/05/2024	4	-16.69	-15.97	-13.69	-15.26	-14.87	-13.80	-17.56	-10.74	-1.27	0.00	0.00	0.00
RTD	06/05/2024	5	-16.88	-15.80	-13.80	-15.36	-15.46	-14.25	-17.56	-10.32	-0.95	0.00	0.00	0.00
RTD	06/05/2024	6	-16.88	-15.46	-13.80	-15.57	-15.26	-13.80	-17.09	-9.45	0.00	0.00	0.00	0.00
RTD	06/05/2024	7	-17.01	-15.97	-15.26	-15.97	-15.46	-15.01	-16.88	-7.43	0.00	0.00	0.00	0.00
RTD	06/05/2024	8	-16.88	-15.97	-14.99	-15.90	-15.41	-13.92	-16.84	0.00	0.00	0.00	0.00	0.00
RTD	06/05/2024	9	-16.88	-15.46	-14.38	-15.37	-15.46	-13.33	-16.84	0.00	0.00	0.00	0.00	0.00
RTD	06/05/2024	10	-16.88	-15.26	-15.07	-15.22	-15.43	-13.62	-16.84	0.00	0.00	0.00	0.00	0.00
RTD	06/05/2024	11	-16.88	-15.16	-15.62	-15.26	-15.09	-13.80	-15.97	0.00	0.00	0.00	0.00	0.00
RTD	06/05/2024	12	-16.88	-14.31	-15.26	-15.34	-15.46	-16.16	-15.46	0.00	0.00	0.00	0.00	0.00

Market	Opr Date	Opr Interval	HE13	HE14	HE15	HE16	HE17	HE18	HE19	HE20	HE21	HE22	HE23	HE24	HE25
RTD	06/05/2024	1	0.00	0.00	0.00	0.00	-2.06	-0.03	0.00	0.00	-0.58	-4.22	0.00	-0.37	
RTD	06/05/2024	2	0.00	0.00	0.00	0.00	-5.21	-3.24	-8.73	0.00	0.00	-8.15	0.00	0.00	
RTD	06/05/2024	3	0.00	0.00	0.00	0.00	-4.38	-0.08	-6.87	0.00	0.00	-12.67	0.00	-1.31	
RTD	06/05/2024	4	0.00	0.00	0.00	-2.25	-1.43	0.00	-3.84	0.00	0.00	-14.96	0.00	-0.99	
RTD	06/05/2024	5	0.00	0.00	0.00	-3.49	-1.18	-2.52	-5.97	0.00	0.00	-15.09	0.00	-7.31	
RTD	06/05/2024	6	0.00	0.00	0.00	-7.46	-0.90	-3.56	-6.71	0.00	0.00	-12.89	0.00	-11.63	
RTD	06/05/2024	7	0.00	0.00	0.00	-2.10	-0.52	-4.35	-11.12	0.00	0.00	-12.75	0.00	-12.13	
RTD	06/05/2024	8	0.00	0.00	-6.42	-4.86	0.00	-0.76	-10.50	0.00	-0.58	-15.45	0.00	-15.20	
RTD	06/05/2024	9	0.00	0.00	0.00	-3.78	0.00	-1.91	-10.36	0.00	-2.04	-15.77	-2.74	-16.28	
RTD	06/05/2024	10	0.00	0.00	0.00	-3.43	0.00	-4.48	-9.13	-5.00	-9.23	-16.51	-1.66	-16.20	
RTD	06/05/2024	11	0.00	0.00	0.00	-0.10	0.00	-2.76	-3.55	-5.72	-9.49	-15.52	-1.07	-16.85	
RTD	06/05/2024	12	0.00	0.00	0.00	0.00	0.00	-5.98	0.00	-0.58	-6.94	-6.64	-1.07	-16.82	

- When the GHG area is net importing, the MC-GHG signals the difference between what the non-GHG area and GHG area are willing to pay for an additional MW from the non-GHG area

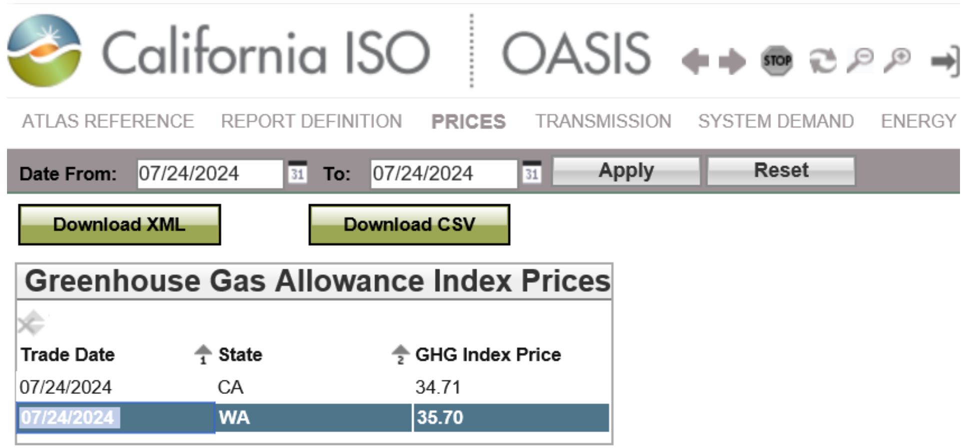
The marginal cost of GHG can change between the 15 and 5 minute markets



Source: Department of Market Monitoring 2023 Annual Report on Market Issues and Performance

GHG Allowance Index Price

- The cost of a resource’s emissions is determined by applicable state regulations.



Trade Date	State	GHG Index Price
07/24/2024	CA	34.71
07/24/2024	WA	35.70

- In California and Washington, an allowance index reflects the cost of purchasing allowances to comply with each state’s GHG pricing program.
  - Resource in these states can account for compliance costs for their state directly in their energy bids.
  - Resources in the WEIM that volunteer capacity to be considered for delivery into a GHG regulated area submit a GHG bid adder that reflects the state-specific cost of compliance..

GHG impacts to GHG regulated areas

- The table below shows average 15 minute market prices in CAISO and the WEIM.
- Between hours-ending 17 and 22, prices in California are generally higher than the rest due to a combination of congestion and GHG costs

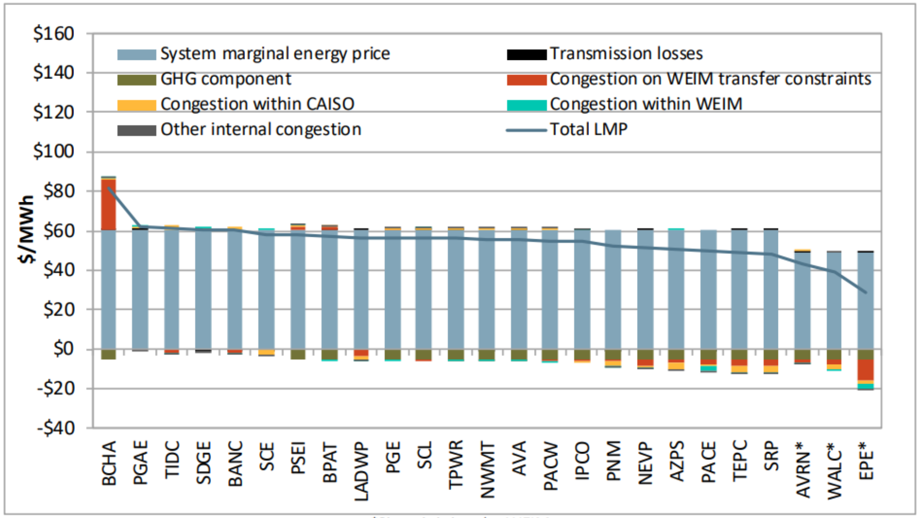
Source: Department of Market Monitoring 2023 Annual Report on Market Issues and Performance

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
SMEC	$59	$57	$56	$56	$59	$66	$71	$61	$47	$42	$40	$38	$36	$37	$39	$49	$61	$80	$101	$108	$90	$77	$68	$61
PG&E (CAISO)	$59	$57	$56	$56	$59	$65	$70	$64	$53	$48	$45	$43	$41	$41	$43	$52	$63	$79	$98	$102	$86	$74	$67	$60
SCE (CAISO)	$60	$57	$56	$56	$59	$66	$71	$58	$38	$32	$29	$26	$26	$27	$30	$43	$57	$79	$104	$115	$94	$81	$70	$62
BANC	$59	$56	$55	$55	$58	$65	$70	$63	$53	$50	$47	$45	$44	$43	$45	$53	$63	$74	$82	$90	$83	$74	$67	$60
Turlock ID	$59	$56	$55	$55	$58	$64	$69	$63	$55	$53	$50	$48	$46	$46	$48	$54	$64	$75	$81	$88	$82	$73	$67	$60
LADWP	$62	$58	$57	$57	$60	$67	$72	$60	$41	$33	$30	$28	$27	$28	$32	$45	$57	$69	$80	$92	$82	$77	$71	$64
NV Energy	$52	$49	$48	$49	$53	$60	$63	$52	$39	$36	$34	$32	$31	$31	$33	$44	$53	$64	$70	$80	$73	$65	$61	$54
Arizona PS	$54	$48	$48	$49	$54	$67	$66	$56	$40	$33	$25	$23	$24	$25	$28	$43	$52	$60	$71	$82	$75	$66	$63	$58
Tucson Electric	$50	$47	$47	$47	$51	$58	$61	$50	$34	$30	$28	$27	$26	$27	$31	$43	$54	$62	$70	$81	$74	$65	$61	$52
Salt River Project	$48	$45	$43	$43	$48	$58	$61	$50	$37	$29	$28	$29	$28	$29	$31	$39	$52	$61	$74	$78	$71	$63	$66	$51
PSC New Mexico	$54	$56	$50	$53	$52	$68	$68	$63	$39	$32	$28	$26	$26	$27	$29	$41	$52	$64	$75	$83	$77	$66	$61	$59
WAPA - Desert SW*	$45	$40	$39	$37	$39	$45	$47	$33	$20	$17	$18	$19	$23	$24	$25	$34	$41	$48	$58	$71	$61	$54	$53	$44
El Paso Electric*	$27	$24	$24	$23	$26	$30	$26	$21	$19	$18	$20	$22	$21	$23	$25	$31	$34	$37	$46	$54	$43	$32	$35	$28
PacifiCorp East	$50	$47	$46	$46	$50	$57	$59	$52	$41	$38	$36	$35	$34	$34	$36	$44	$52	$58	$65	$73	$67	$60	$58	$51
Idaho Power	$53	$50	$49	$50	$54	$61	$65	$58	$50	$47	$45	$44	$43	$43	$44	$50	$57	$63	$68	$74	$70	$63	$62	$54
NorthWestern	$52	$50	$49	$50	$54	$63	$64	$59	$54	$50	$47	$47	$46	$45	$46	$53	$62	$63	$67	$72	$69	$62	$62	$54
Avista Utilities	$53	$50	$49	$50	$54	$62	$63	$59	$53	$51	$49	$48	$48	$47	$47	$52	$59	$63	$66	$70	$68	$62	$62	$55
Avangrid*	$40	$37	$36	$37	$39	$45	$44	$39	$39	$40	$40	$40	$41	$42	$41	$44	$47	$49	$49	$53	$52	$47	$49	$42
BPA	$54	$50	$49	$49	$53	$61	$61	$57	$55	$54	$53	$51	$51	$51	$50	$56	$61	$65	$69	$73	$70	$63	$64	$54
Tacoma Power	$53	$50	$49	$50	$53	$59	$60	$56	$53	$53	$52	$51	$50	$50	$49	$53	$58	$62	$67	$71	$66	$60	$63	$54
PacifiCorp West	$52	$49	$48	$49	$53	$60	$60	$56	$52	$51	$50	$49	$49	$47	$47	$52	$58	$63	$64	$67	$65	$60	$61	$54
Portland GE	$53	$50	$49	$50	$53	$59	$61	$57	$53	$52	$51	$50	$50	$48	$49	$55	$59	$66	$70	$72	$68	$61	$61	$54
Puget Sound Energy	$54	$49	$48	$50	$54	$59	$60	$56	$55	$56	$53	$51	$51	$53	$49	$56	$63	$71	$73	$79	$69	$63	$63	$54
Seattle City Light	$56	$50	$49	$50	$53	$59	$59	$56	$53	$53	$51	$51	$51	$51	$50	$54	$58	$62	$67	$71	$67	$62	$61	$54
Powerex	$72	$67	$66	$67	$69	$75	$83	$87	$86	$83	$84	$82	$82	$81	$82	$86	$91	$93	$93	$94	$92	$87	$83	$74

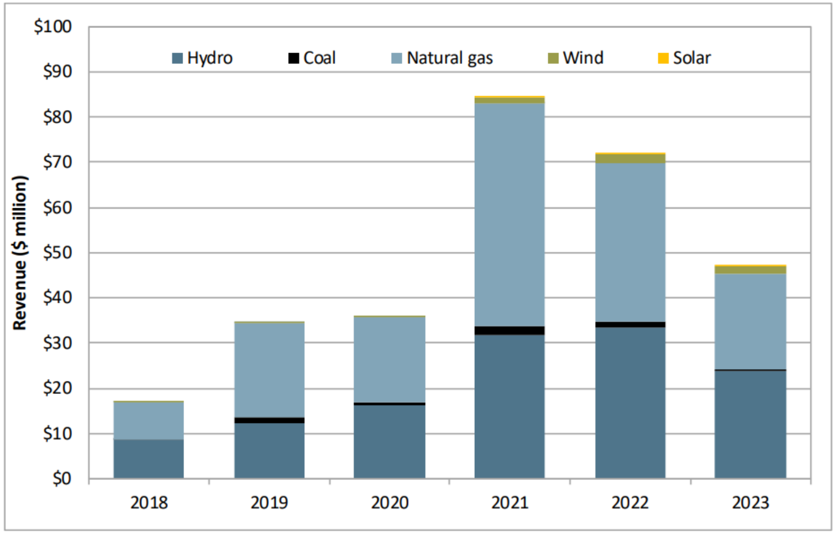
*Since joining the WEIM

GHG revenue allocation in the WEIM today

- **The table on the right** shows the impact, on average, of the GHG component on 15 minute prices in WEIM BAs
- GHG is represented as a negative component of LMPs, bringing down the average price in those BAs.



*Since joining the WEIM



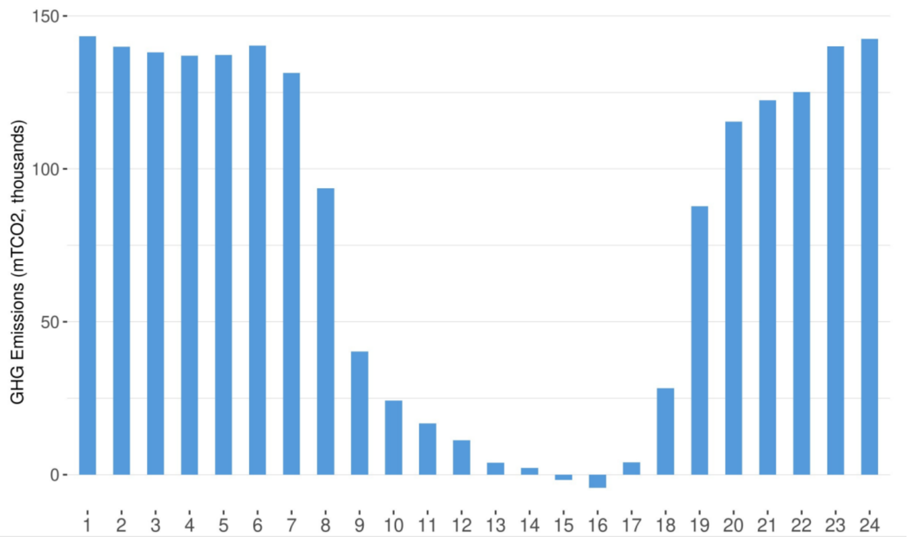
- **The table on the left** shows annual GHG revenue accruing to WEIM resources attributed to California by fuel type.
- In 2023, natural gas received 45% of revenue and hydroelectric 50% of annual GHG revenue

Source: Department of Market Monitoring 2023 Annual Report on Market Issues and Performance

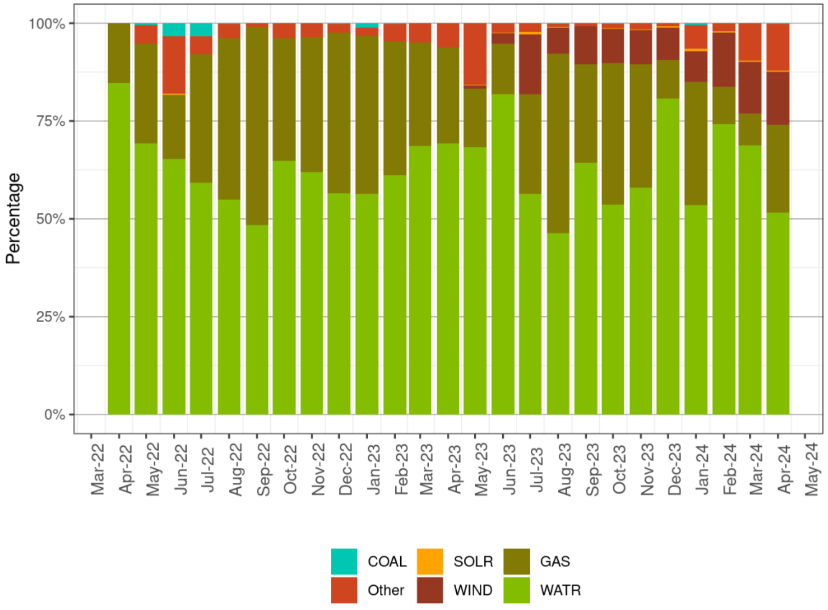
GHG Emissions Tracking for the CAISO BAA and CA BAAs

The ISO publishes emissions data specifically for the ISO BA and BAs in the jurisdiction of California's GHG pricing policy.

Hourly GHG Emissions serving ISO Load, April 2024



% of MWh transfers of GHG attributions into California BAs



Key takeaways

- Compliance costs associated with GHG pricing policies have implications for least-cost dispatch and efficiency in a broad, regional market.
- The goal of price formation with GHG is to ensure dispatch and prices are consistent with different jurisdictional GHG preferences, and settled appropriately.
- When preferences for dispatch and prices between the GHG and non-GHG areas diverge, the MC-GHG, a component of LMPs, makes that cost separation transparent.

The next three chapters will incrementally illustrate, and iterate on, these concepts. Hang in there!

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Chapter 2

OPTIMIZATION BASICS

Optimization Basics Overview

- Looking forward to **Chapter 4,** we're going to:
  - determine what resources are economic for dispatch and to be attributed to the GHG area,
  - determine how to set prices, and
  - discuss how price formation with GHG relates to basic price formation principles

- In this chapter, we'll will review the concepts above without GHG, and lay out some basic price formation principles.

- For more on how the market optimization works, the Appendix of this presentation contains links to additional materials from the ISO's Learning Center.

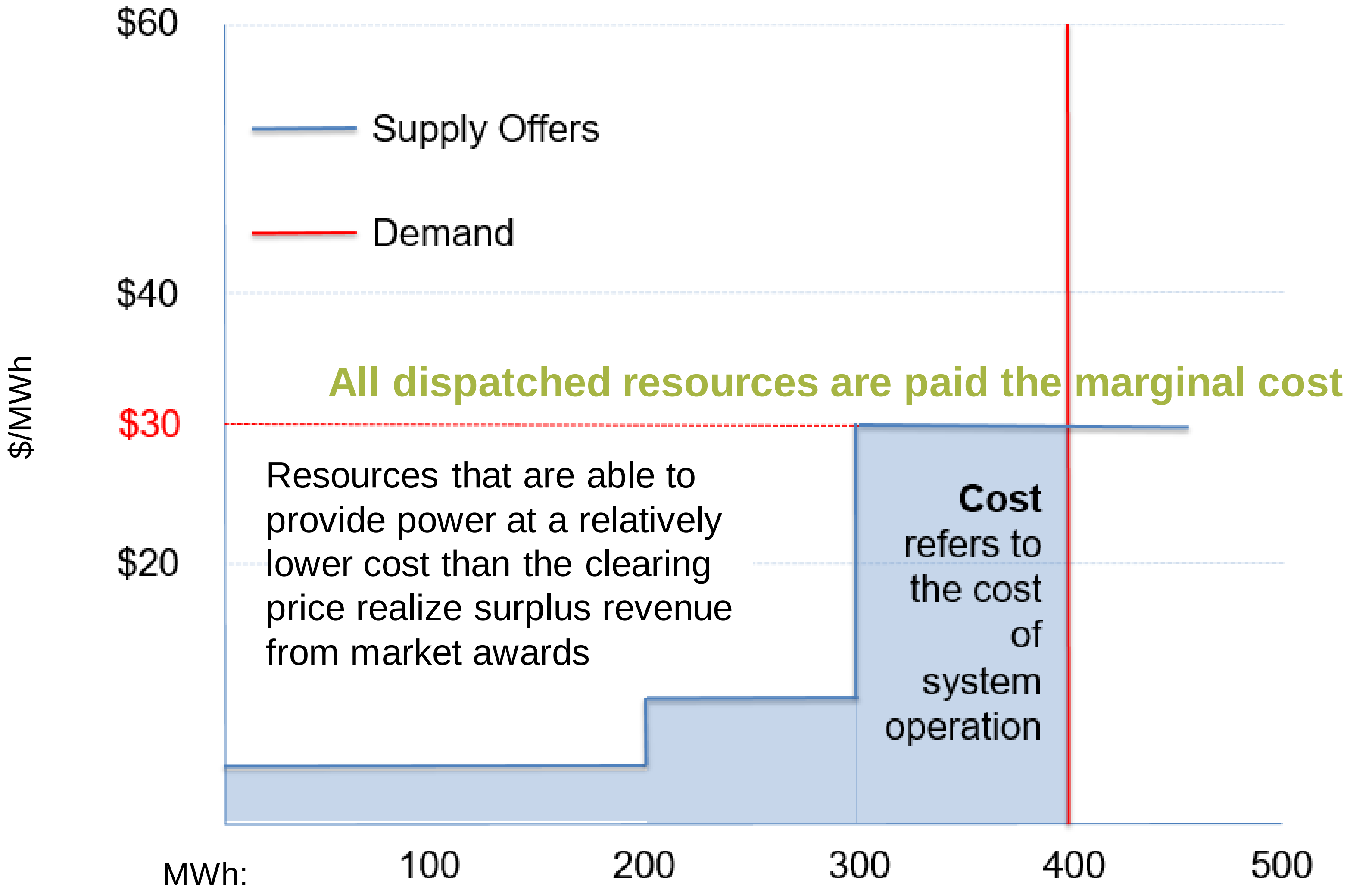
Basic terms and concepts in this presentation

- **Locational Marginal Price (LMP):** Resources respond to the price signal at their location, which signals the marginal cost of the next increment of capacity needed to meet load.

- **Bid price, marginal cost, and total cost:** A resource's bid price represents the cost of incremental capacity from that resource, or a resource's marginal cost. The total cost of the resource is the aggregate cost of capacity.
  - *Resource bids $10/MWh and dispatched to 10MW, total cost is $100*

- **Surplus**: In this presentation, we'll identify surplus payments where infra-marginal resources receive a surplus payment above their bid price.

Cost savings and efficiency come from least-cost dispatch and price formation



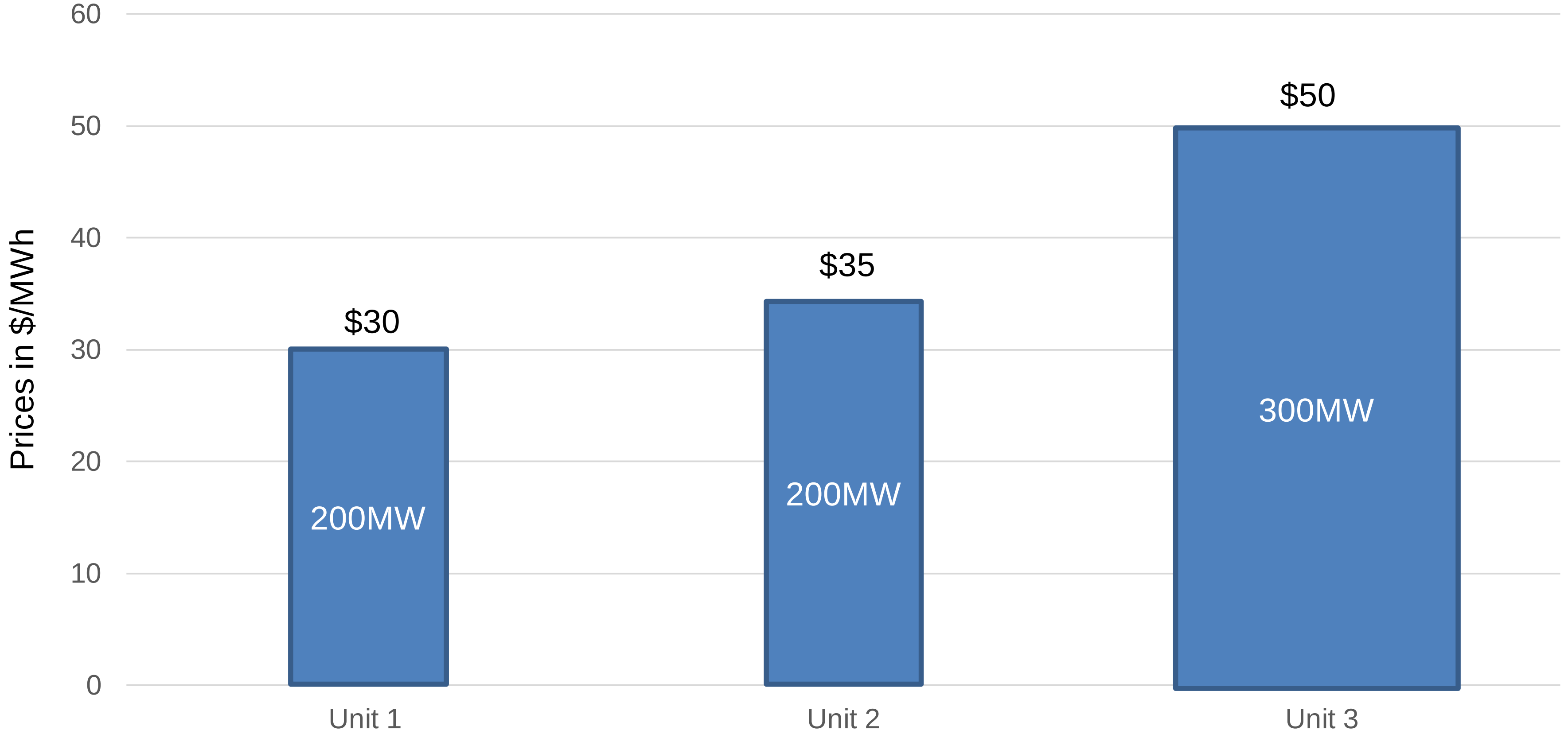
Common Price Formation Principles

- Prices should provide a sufficient incentive for resources to follow their dispatch instructions:

  – The marginal resource setting the price makes $0 profit, and is indifferent to dispatching capacity across its operational range

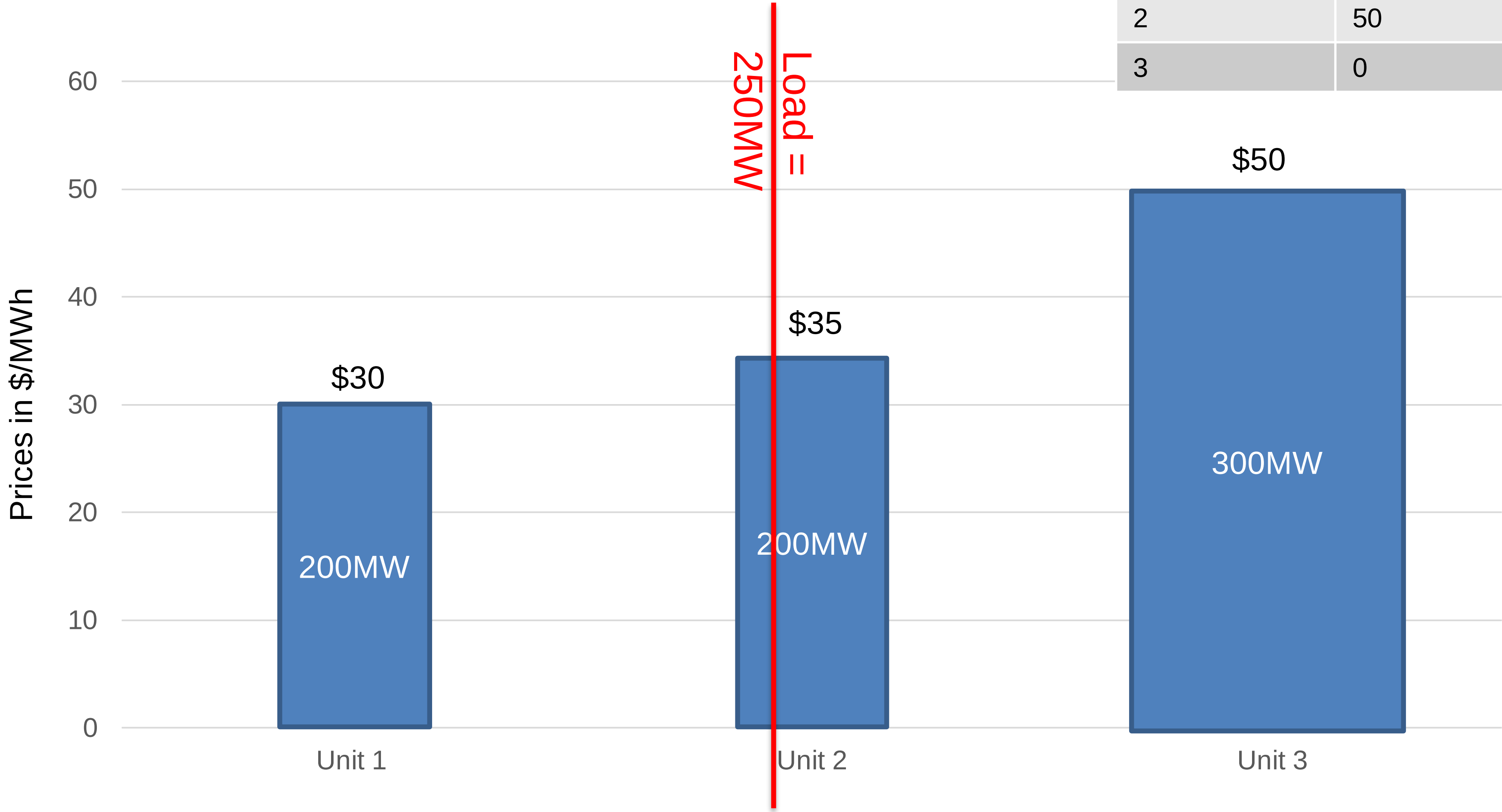
  – Resources that are able to dispatch at a relatively lower cost than the marginal resource have an incentive to dispatch their full capacity

How do we dispatch these resources to meet 250MW of load?



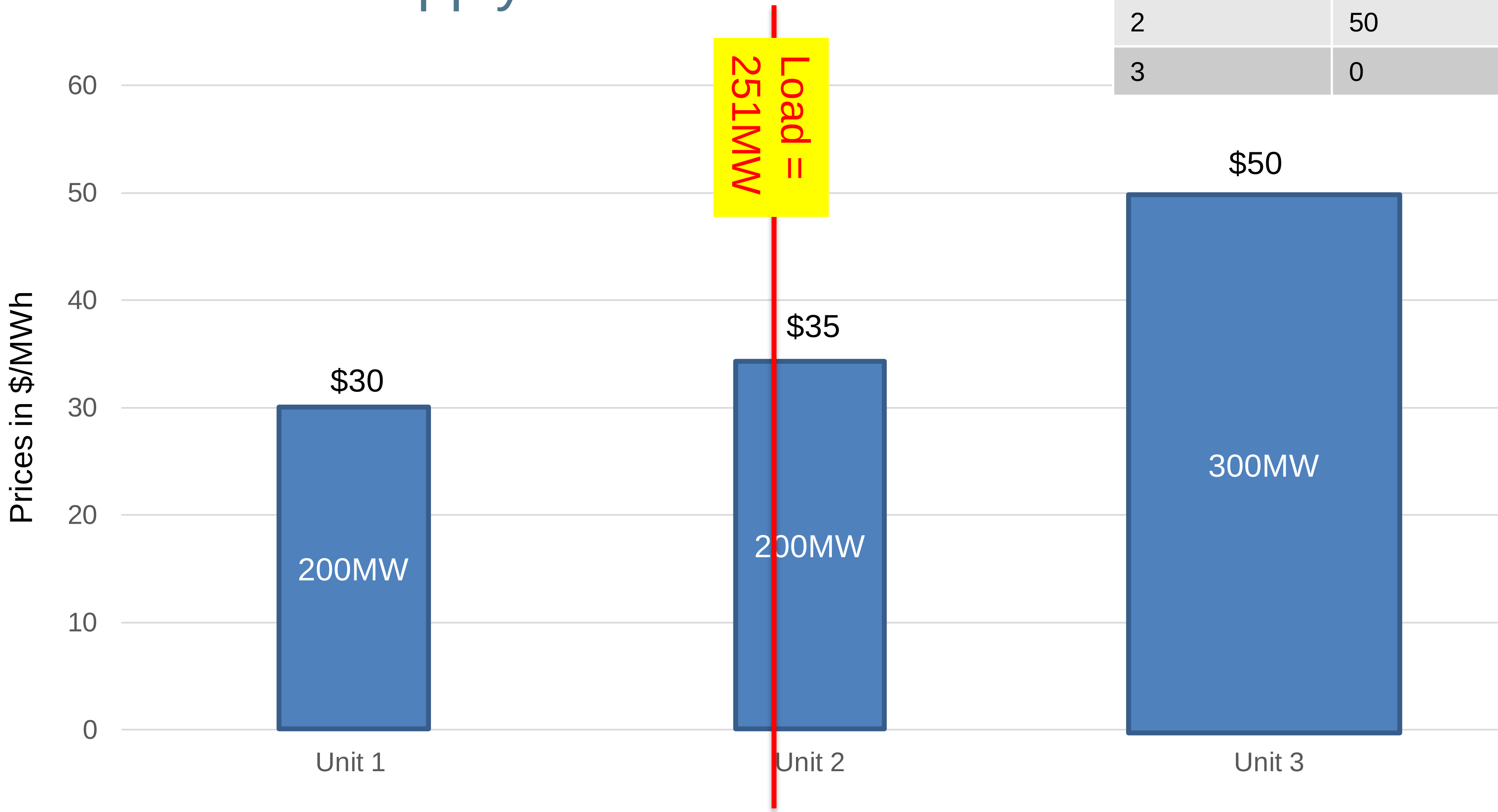
How do we dispatch these resources to meet 250MW of load?

Unit	Dispatch (MW)
1	200
2	50
3	0



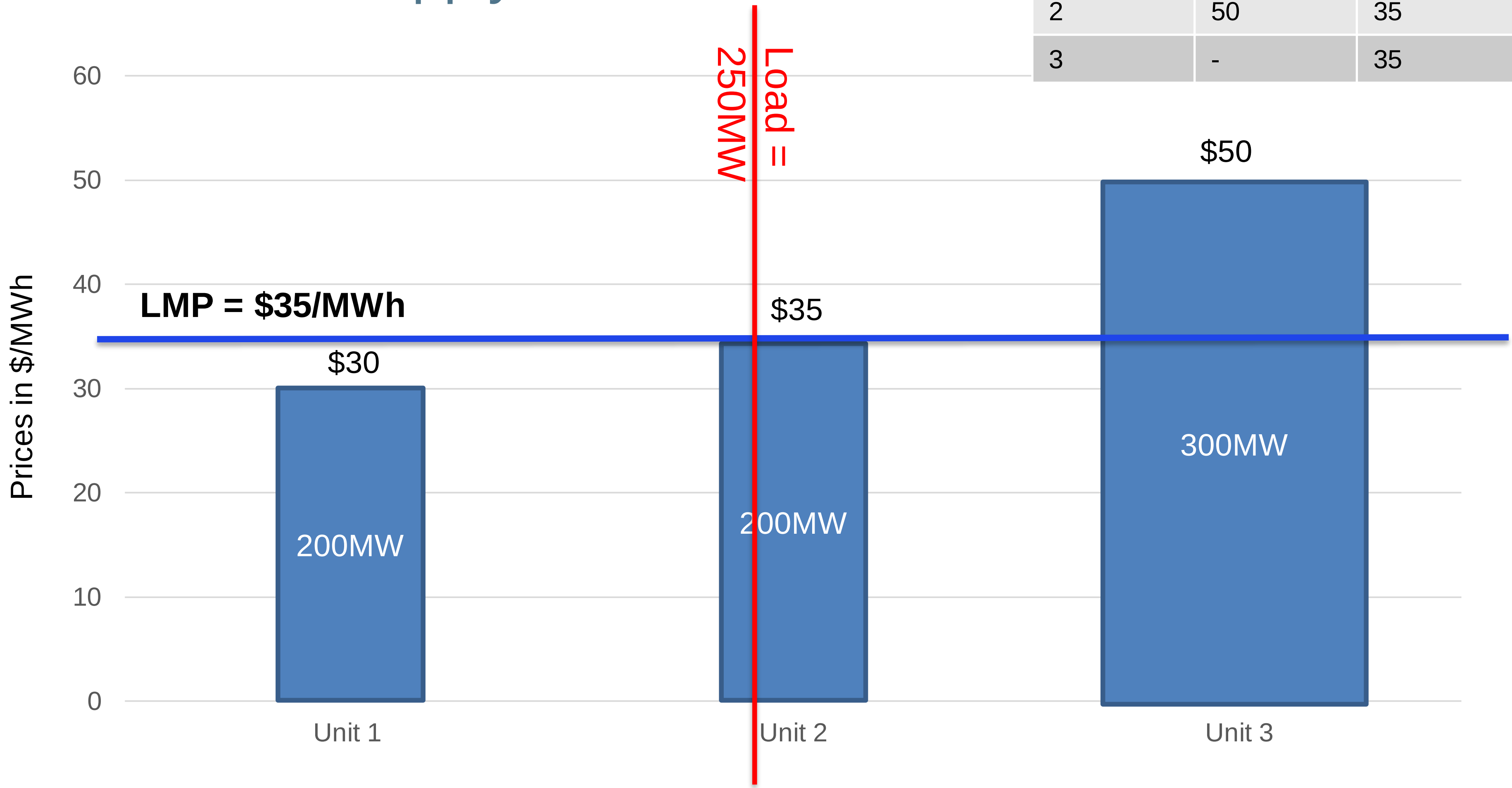
How do we set prices to incentivize 250MW of supply at least cost?

Unit	Dispatch (MW)
1	200
2	50
3	0



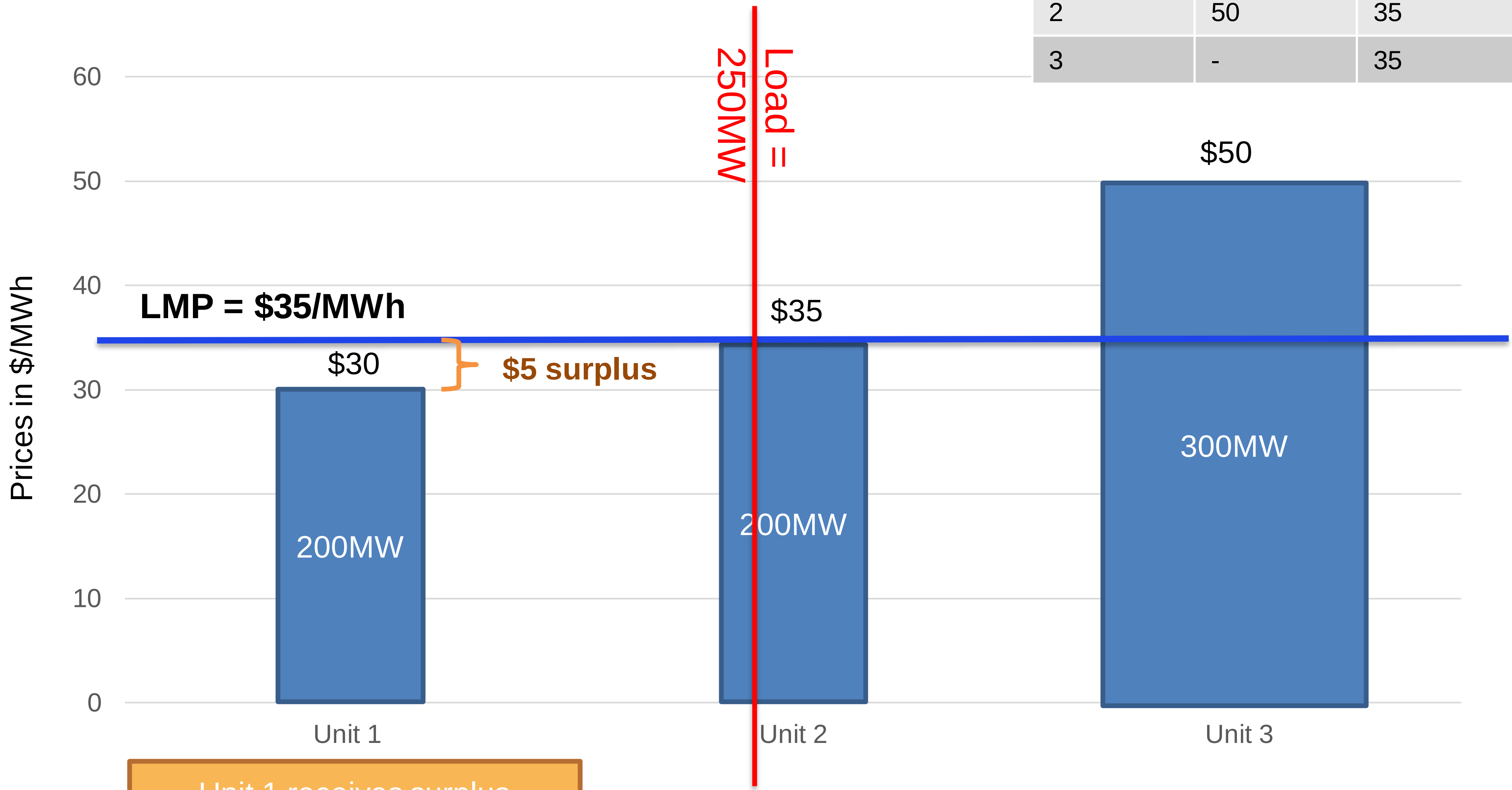
How do we set prices to incentivize 250MW of supply at least cost?

Unit	Dispatch (MW)	LMP ($/MWh)
1	200	35
2	50	35
3	-	35



Prices are efficient

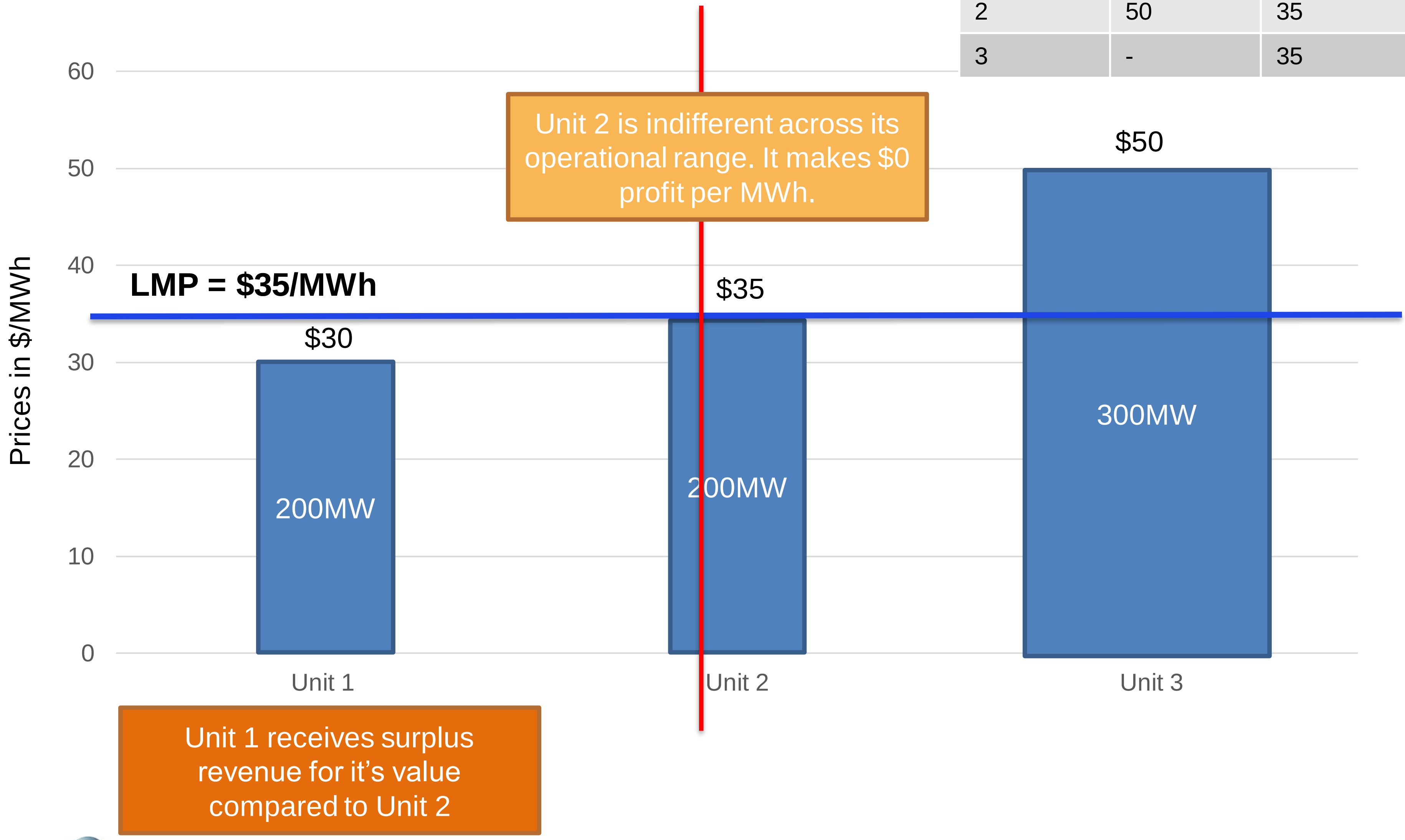
Unit	Dispatch (MW)	LMP ($/MWh)
1	200	35
2	50	35
3	-	35



Unit 1 receives surplus revenue for it's value compared to Unit 2

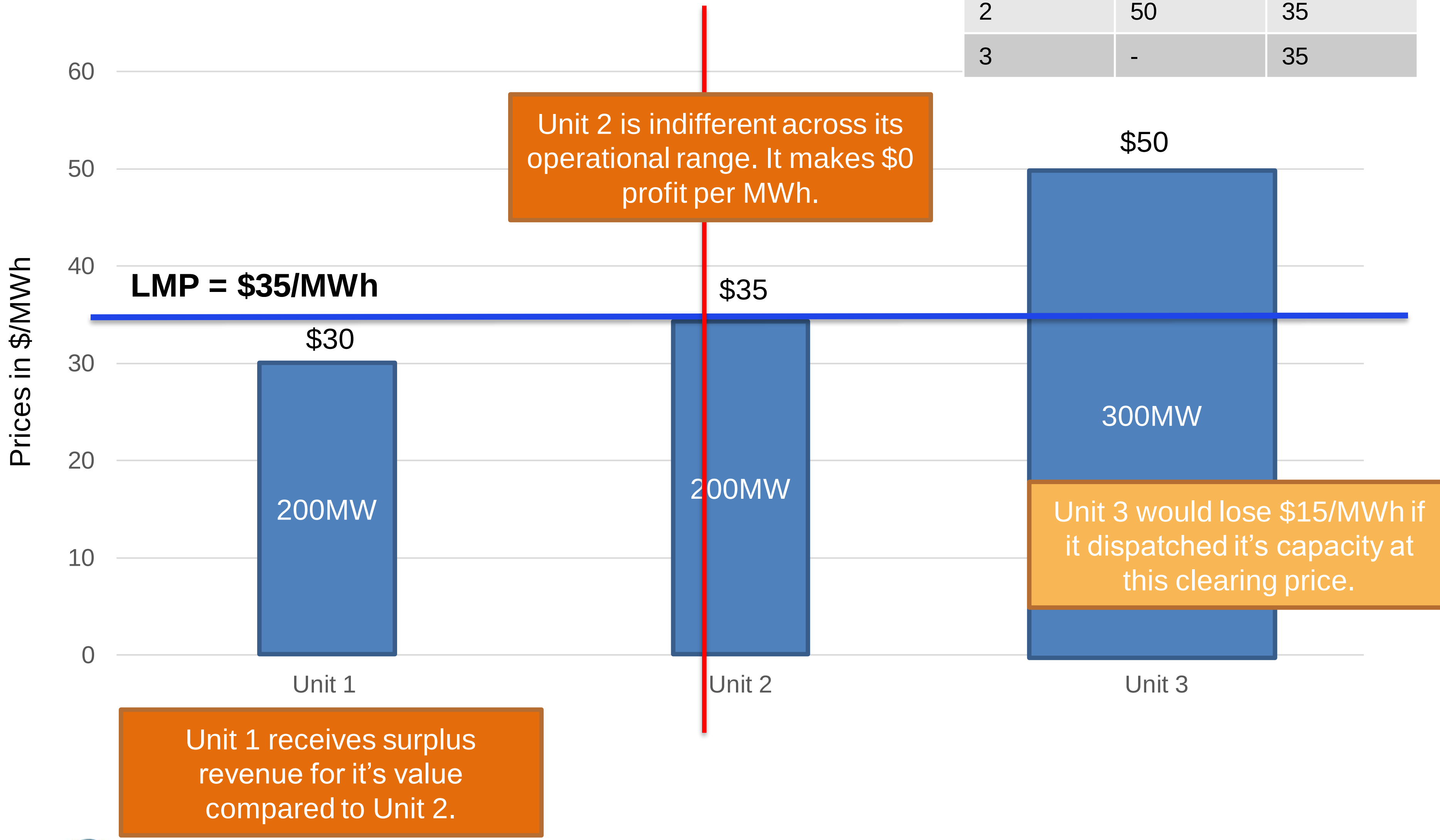
Prices are efficient

Unit	Dispatch (MW)	LMP ($/MWh)
1	200	35
2	50	35
3	-	35



Prices are efficient

Unit	Dispatch (MW)	LMP ($/MWh)
1	200	35
2	50	35
3	-	35



Accounting for load in separate areas and a physical transmission constraint

- In the previous example, a single LMP reflected the cost of the marginal unit.
  - The next example, and later examples in Chapter 4, will have two areas with two separate LMPs.

- With unlimited transmission, a single unit anywhere could set the market clearing price everywhere but price separation could still come from separate GHG preferences.

- Understanding how a transmission constraint creates price separation will help illustrate when price separation is due to GHG.

Example set up

The following example has two balancing authority areas, separated by a transmission constraint:

In Balancing Area 1:

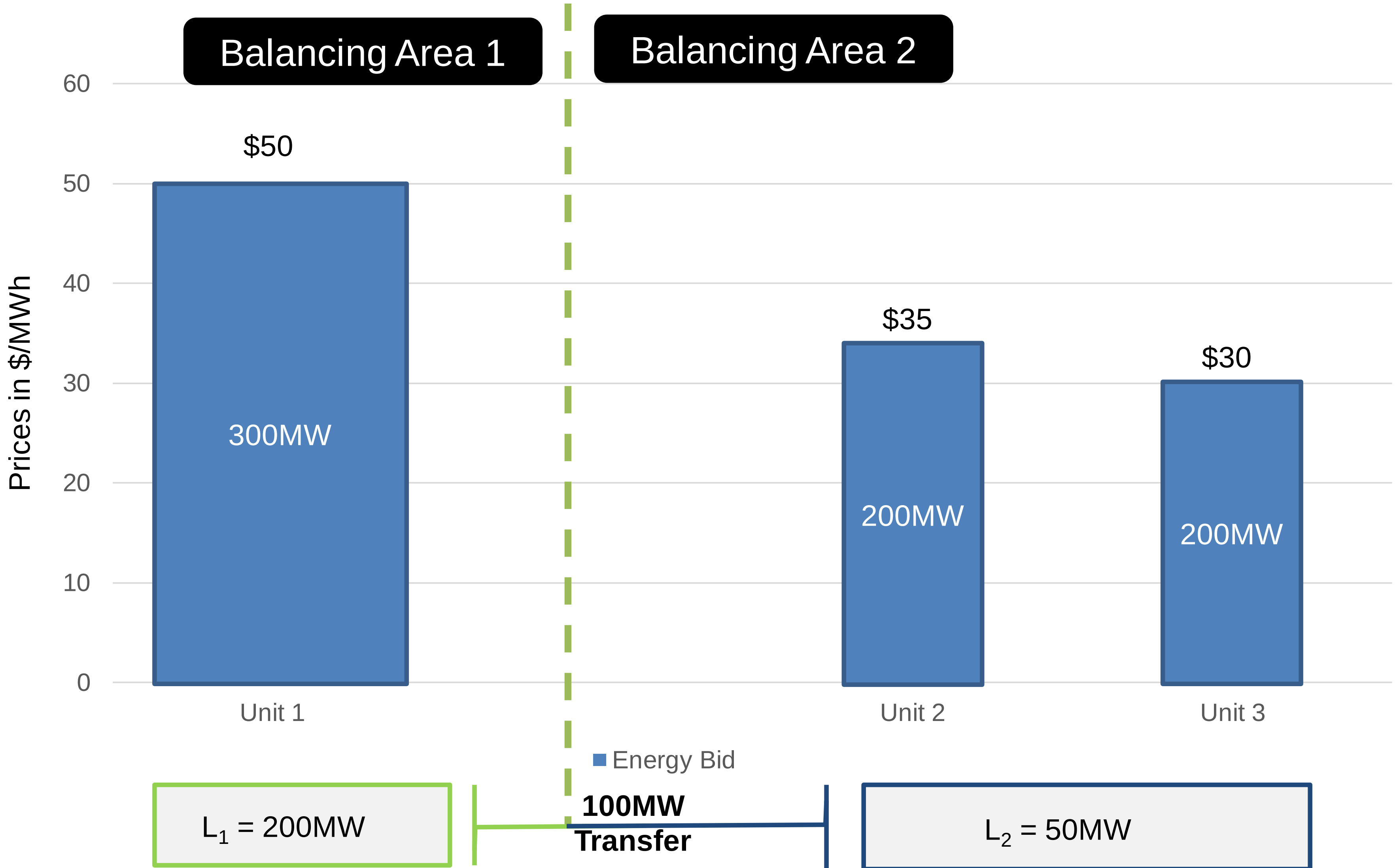
Unit 1 is a 300MW unit. Unit 1's bid price is $50/MWh.

In Balancing Area 2:

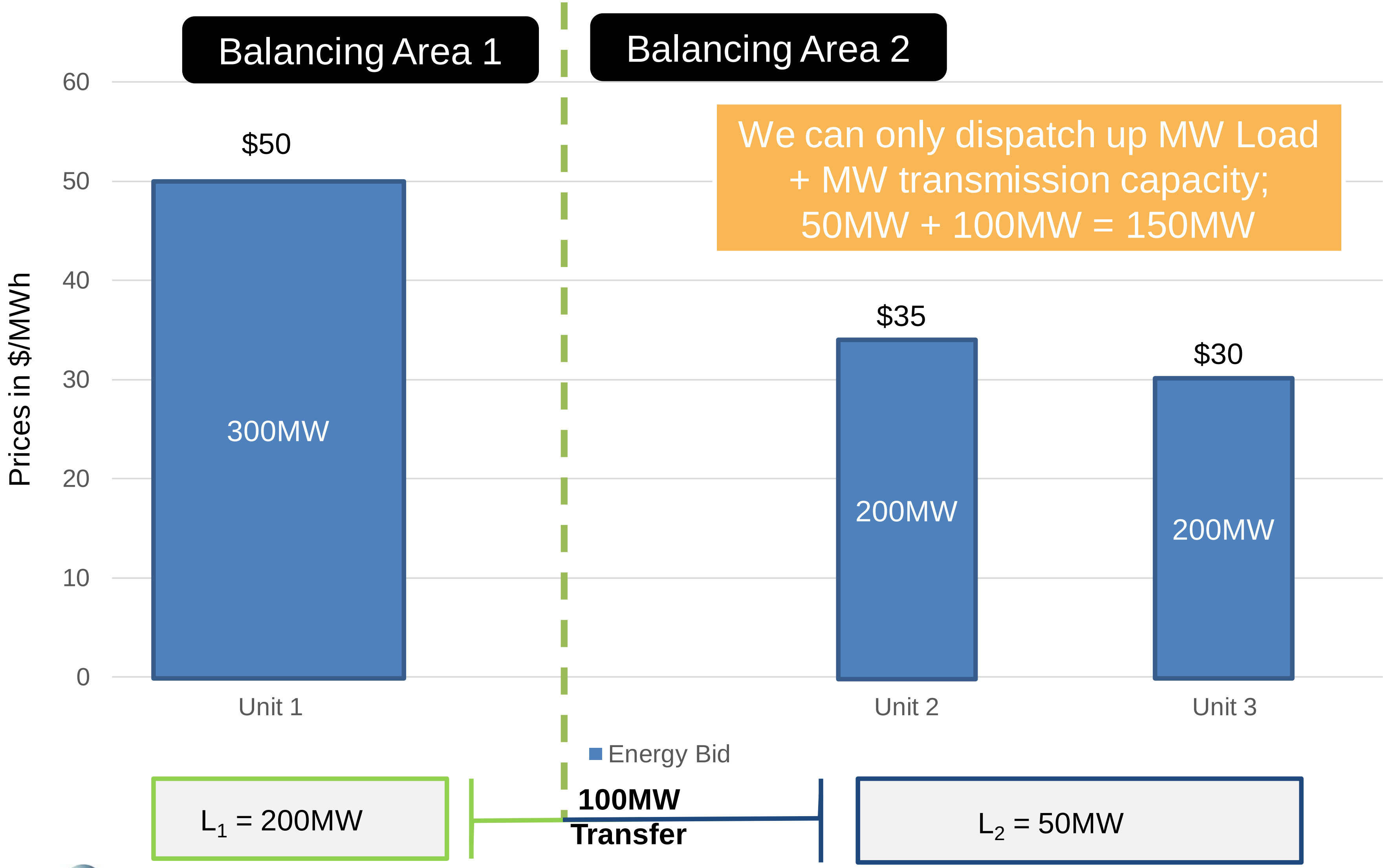
Units 2 and 3 are both 200MW units and cost $35/MWh and $30/MWh respectively.

Load in each area is labeled at the bottom. Load in BA1 is 200MW, and load in BA2 is 50MW. The two areas are separated by a transmission constraint that limits transfers between them to 100MWs.

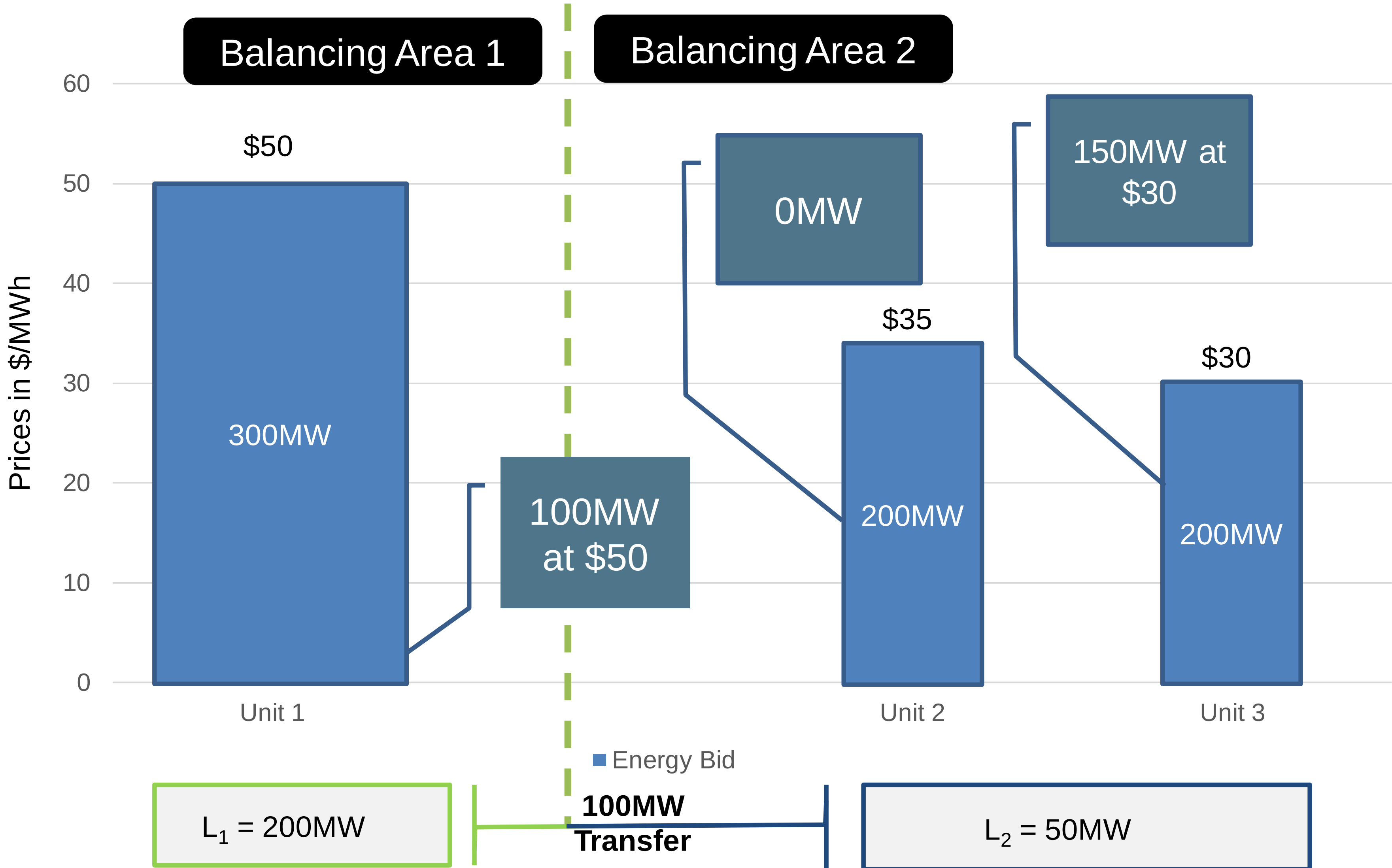
Accounting for a physical transmission constraint



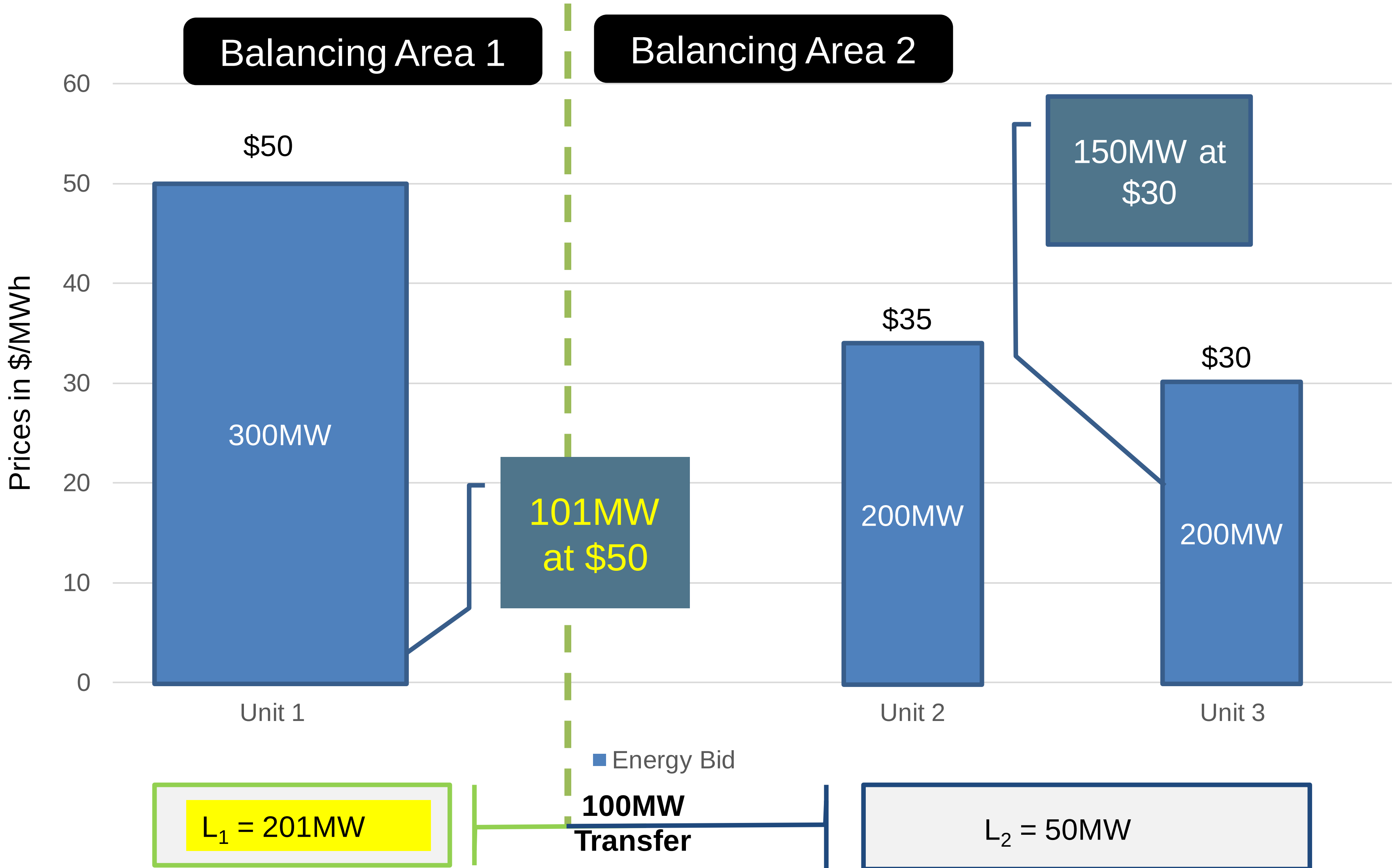
Accounting for a physical transmission constraint



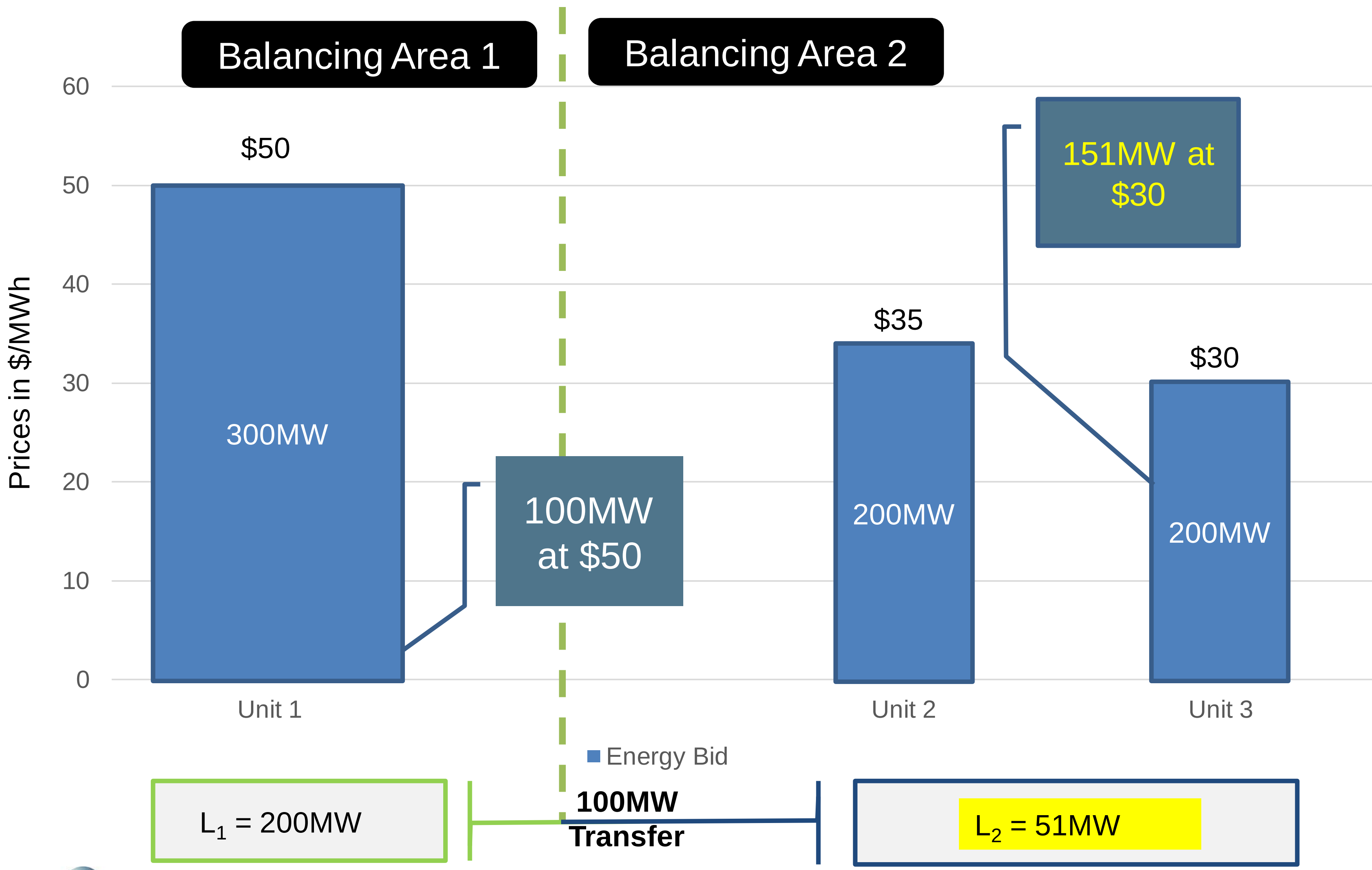
Accounting for a physical transmission constraint



Accounting for a physical transmission constraint



Accounting for a physical transmission constraint

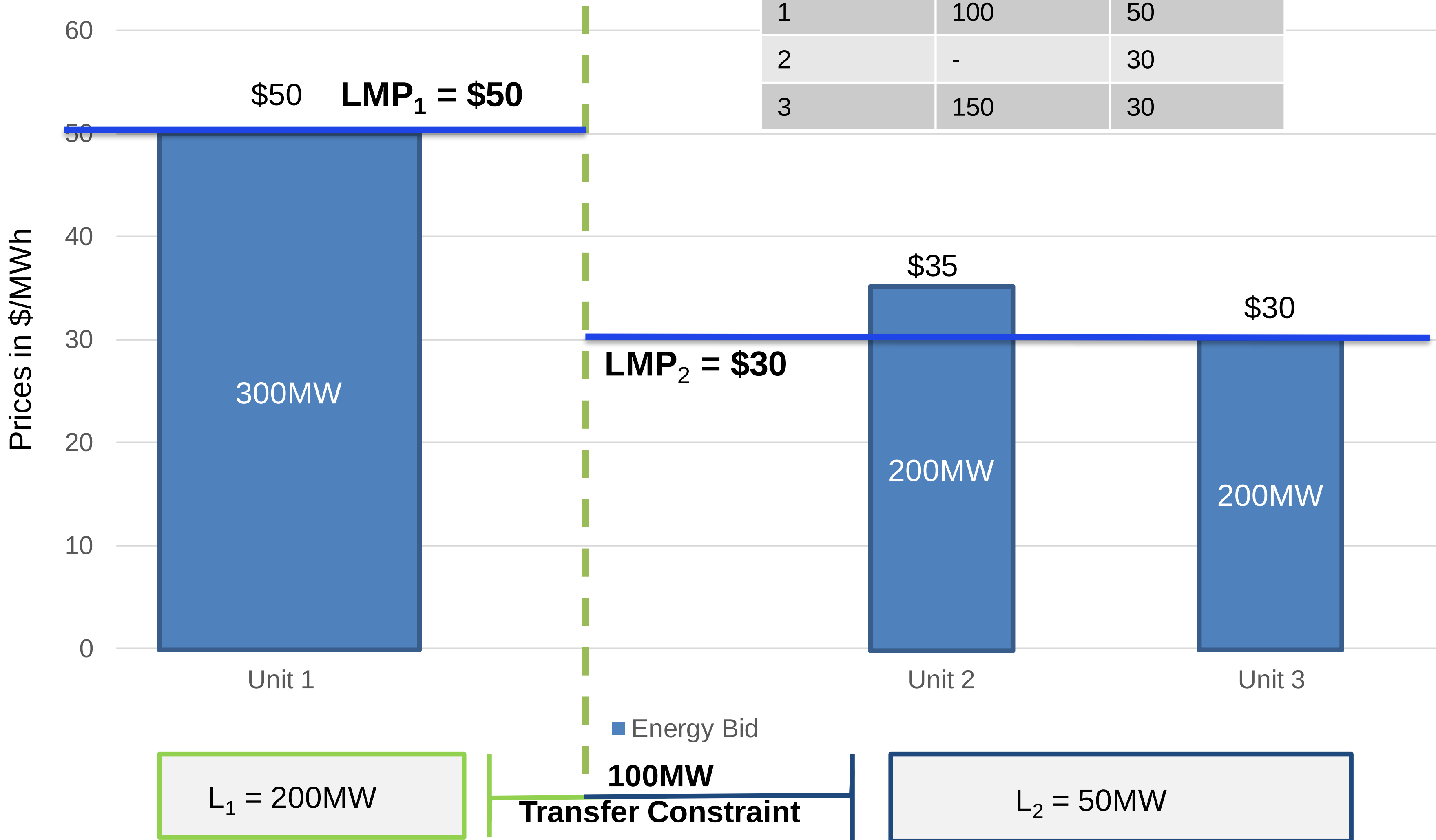


Determining the LMP in each area

- The LMPs can be verified by increasing load in each area
  - Increasing Load in BA1 by 1MW incurred an additional cost of $50/MWh
  - Increasing Load in BA2 by 1MW incurred an additional cost of $30/MWh

Accounting for a physical transmission constraint

Unit	Dispatch (MW)	LMP ($/MWh)
1	100	50
2	-	30
3	150	30



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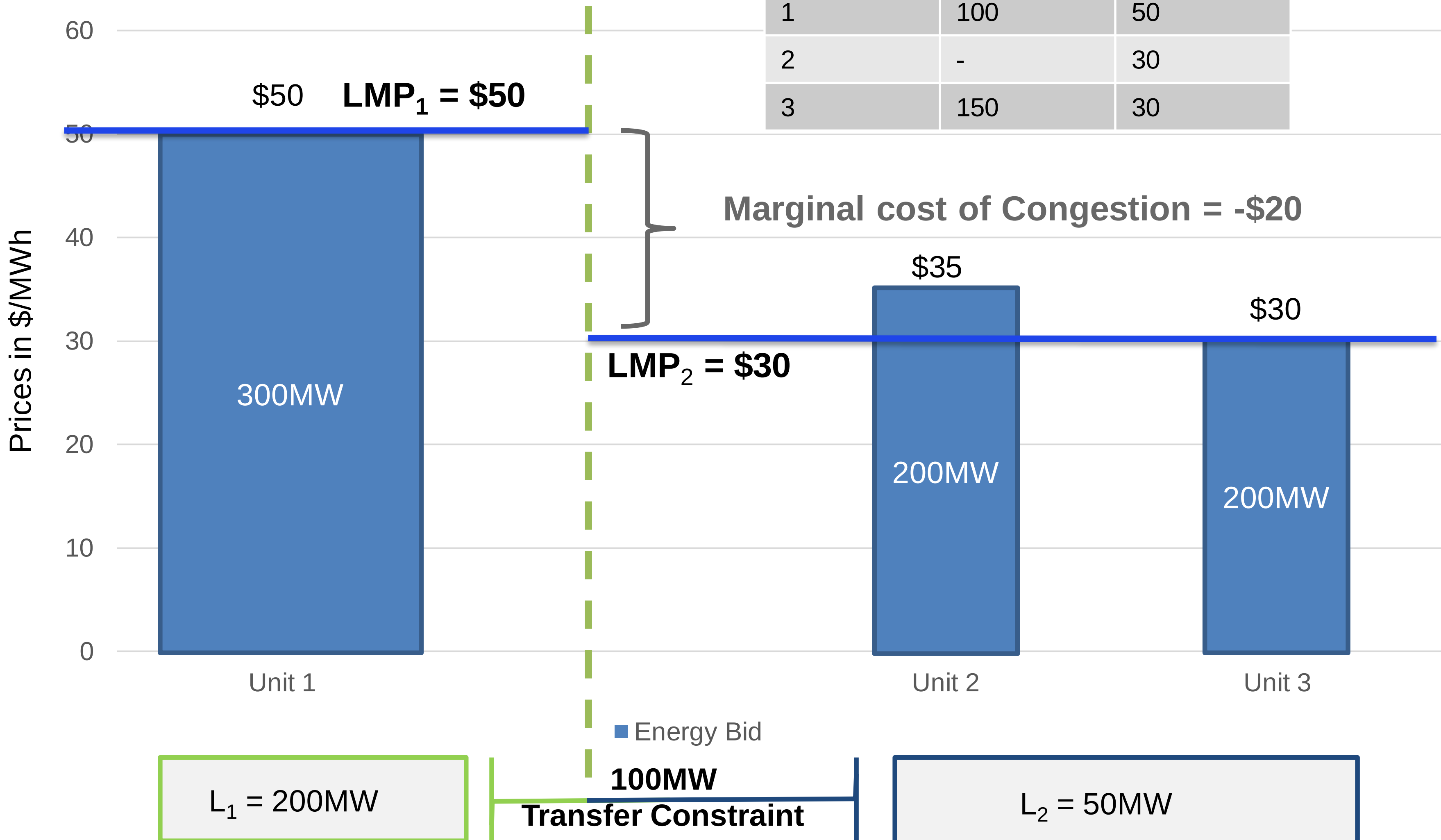
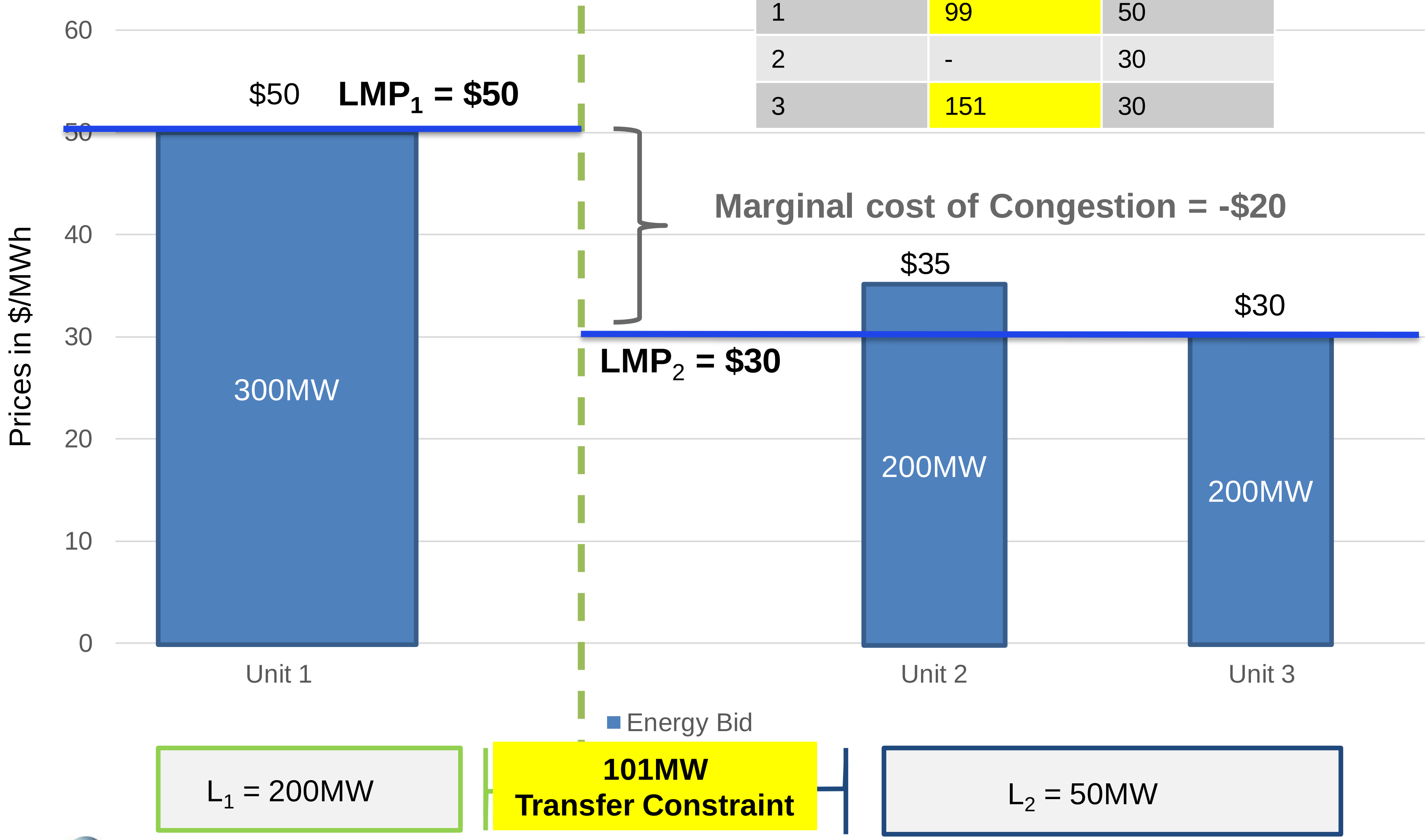
Accounting for a physical transmission constraint

Unit	Dispatch (MW)	LMP ($/MWh)
1	100	50
2	-	30
3	150	30



Accounting for a physical transmission constraint

Unit	Dispatch (MW)	LMP ($/MWh)
1	99	50
2	-	30
3	151	30



Marginal cost of congestion

- The marginal cost of congestion can be verified by relaxing the transfer limit by 1MW and re-solving optimal dispatch.

- In the prior example, a 101MW transfer limit allows us to use 1MW of Unit 3 to displace 1MW of Unit 3 for a total $20 savings to total system cost.

Overview of GHG Price Formation Evergreen Training

- Chapter 1: Background and Context
- Chapter 2: Optimization Basics
- Chapter 3: Optimizing with GHG
- Chapter 4: Examples of Price Formation with GHG

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Chapter 3

OPTIMIZING WITH GHG

Key concepts

- Separable **GHG bid adders** allow the market to dispatch at least cost, consistent with separate jurisdictional preferences
  - Prevents the cost of one jurisdiction's GHG policy from impacting costs in the rest of the market
- The **GHG export allocation** tells the market how many MW of capacity to attribute to a GHG area
- The **marginal cost of GHG**, a value produced by the market optimization, is a shadow price for allocating an additional MW to the GHG area
  - Ensures the efficiency of price formation and market outcomes

GHG Accounting with GHG bid adders

A resource can submit a two part GHG bid adder for each GHG area:

- MWh quantity the resources is willing to offer to the GHG area
- $/MWh cost associated with the resources expected compliance obligation in the GHG area

A resource does not need a bid adder for it's own jurisdiction

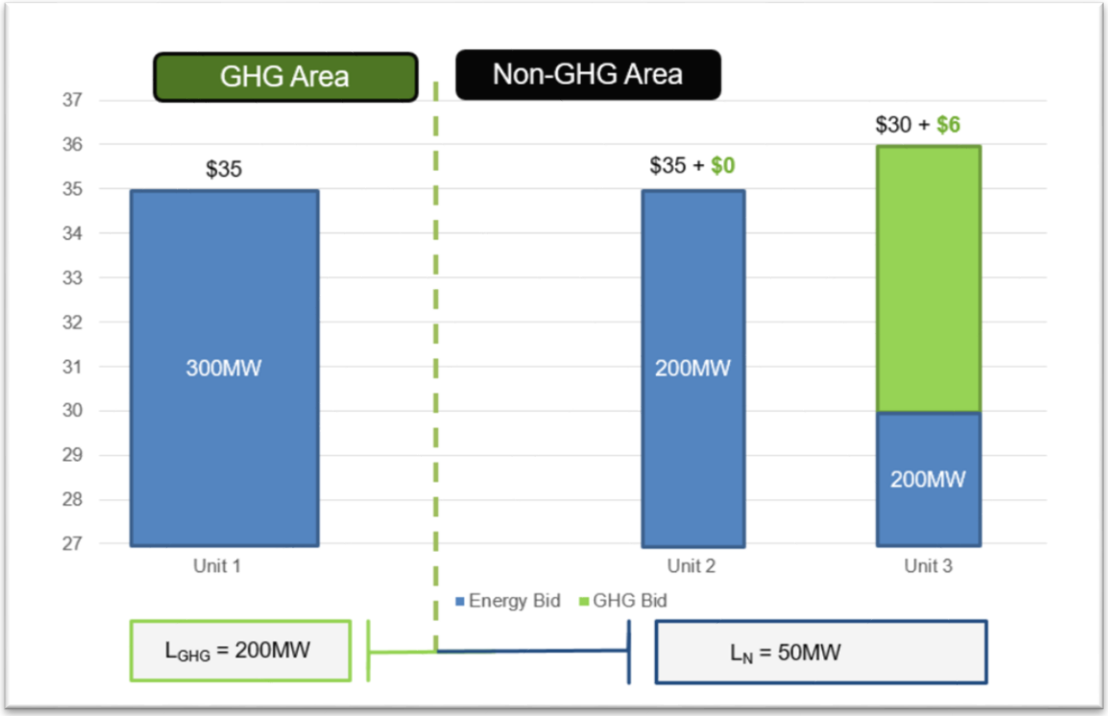
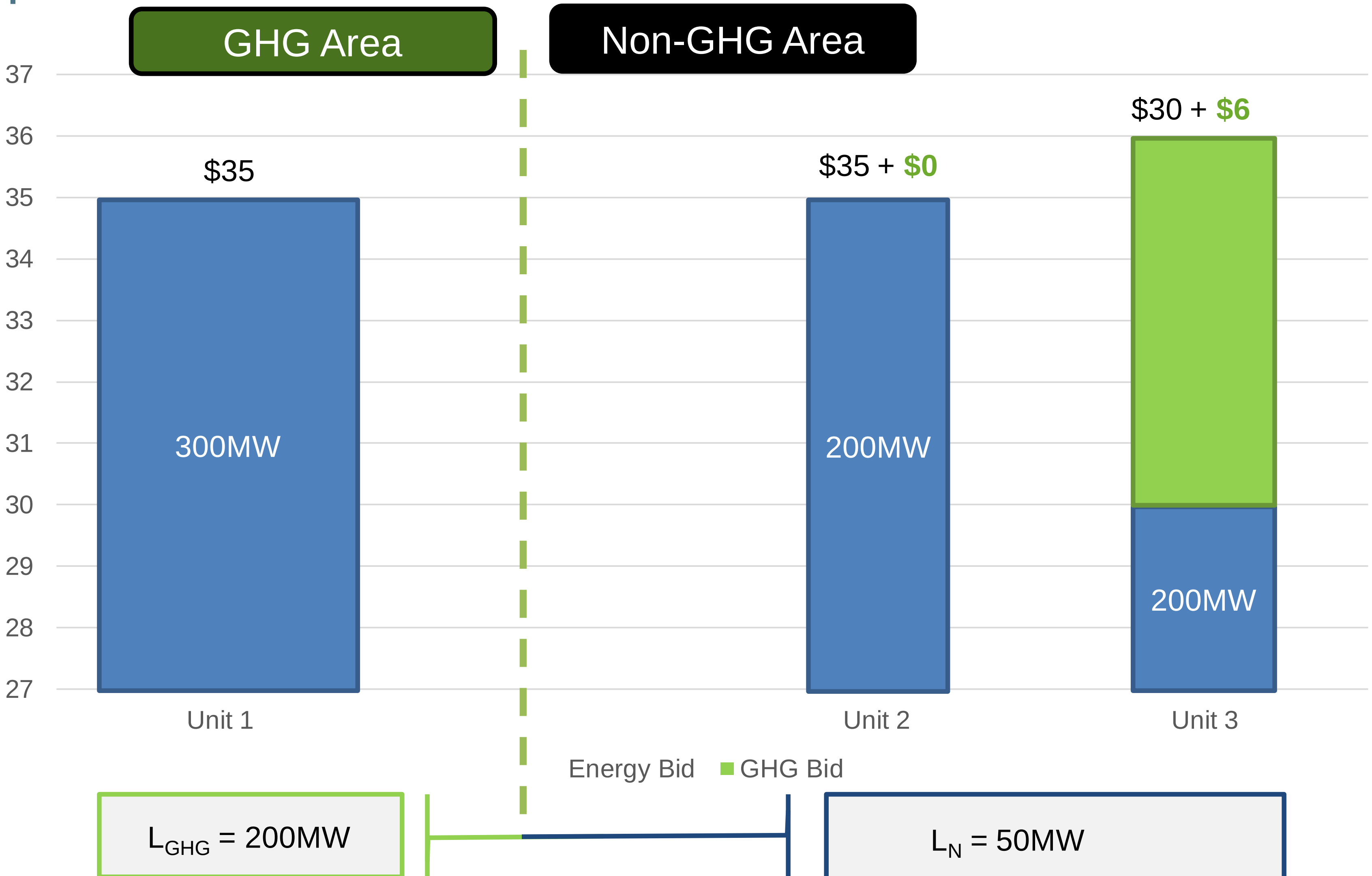


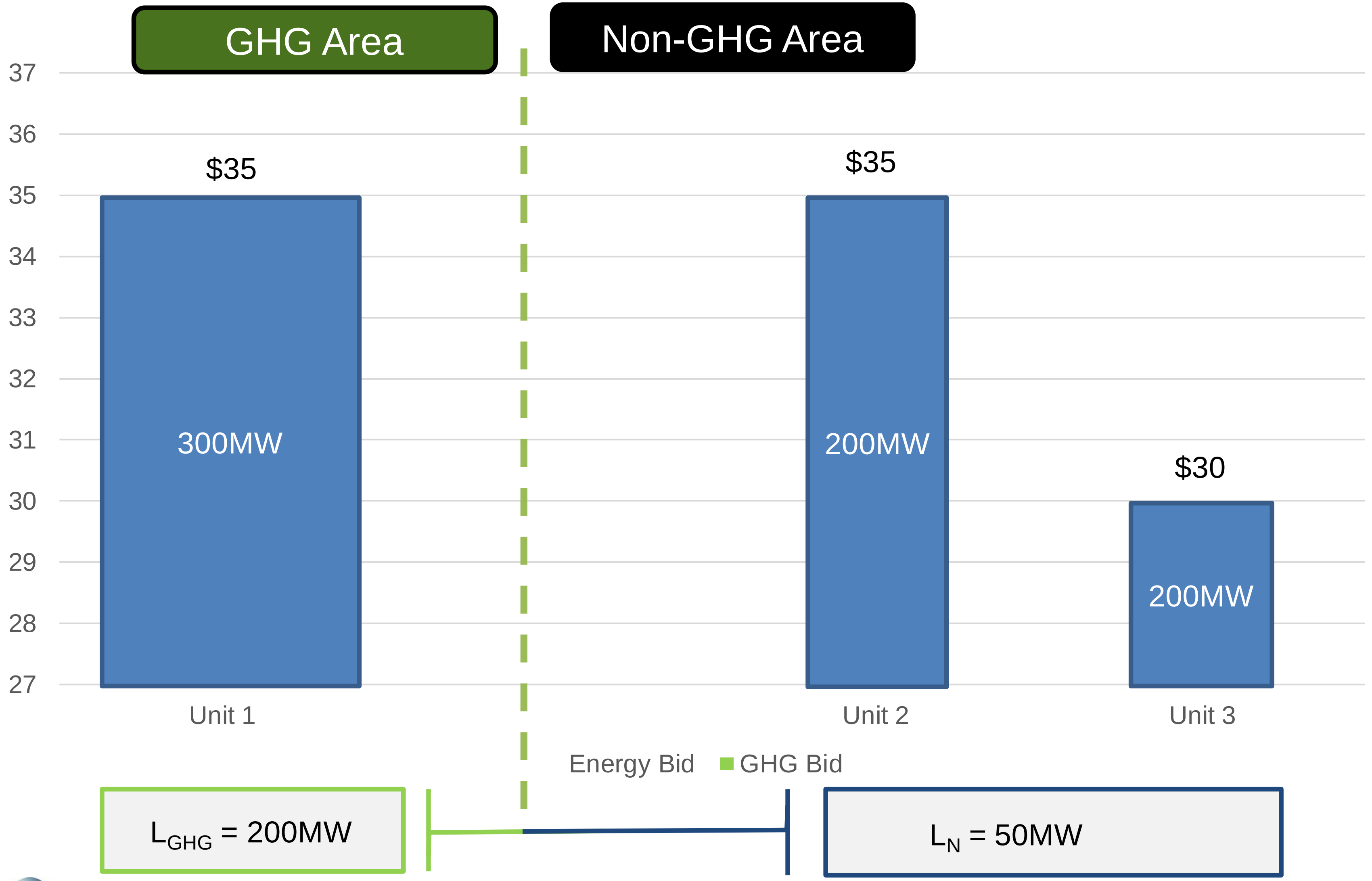
Table: two part bid adders for example resources

Resource	MWh Quantity	$/MWh GHG bid
Unit 1	N/A	N/A
Unit 2	200MWh	$0/MWh
Unit 3	200MWh	$6/MWh

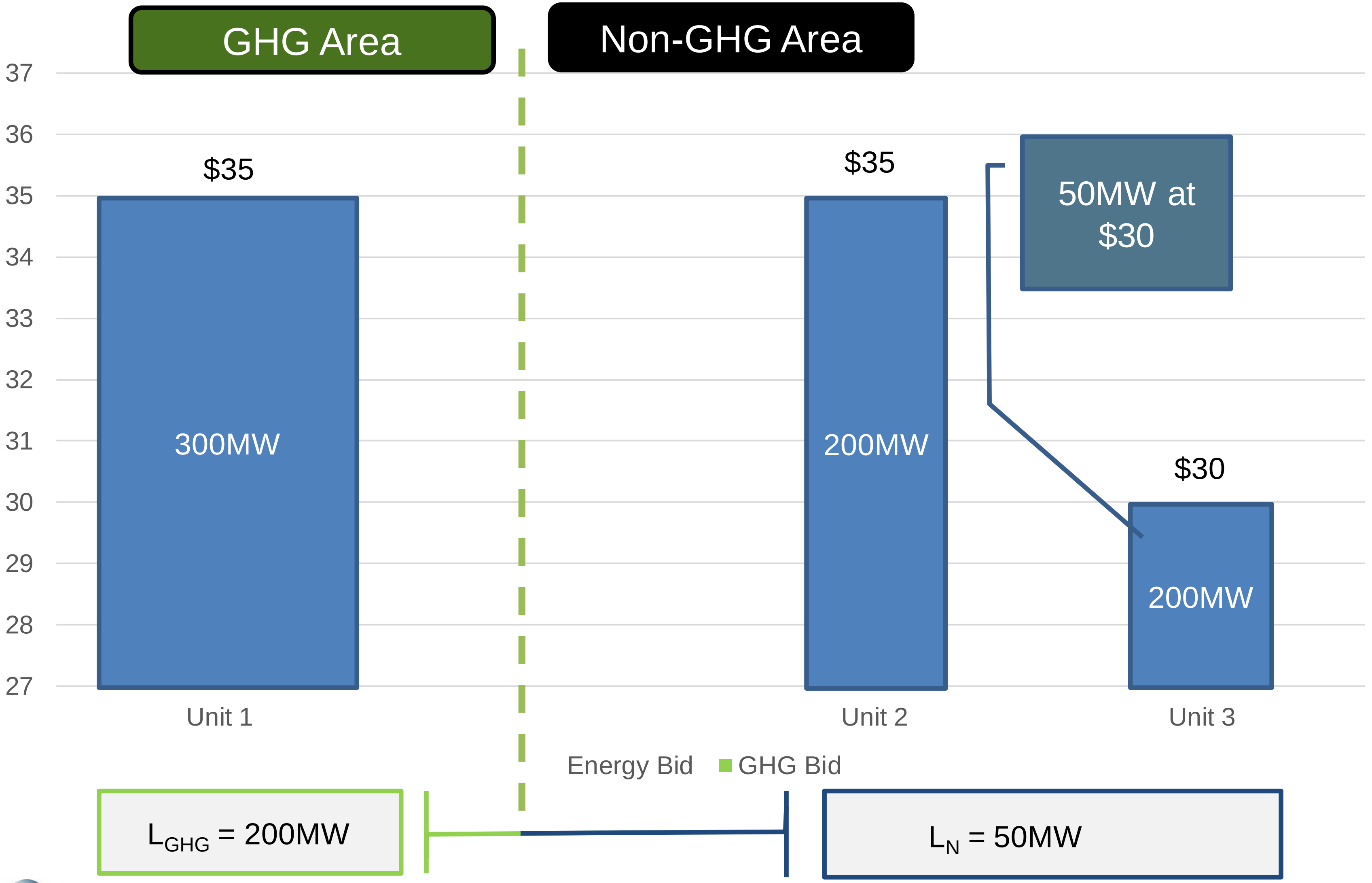
The market tries to satisfy GHG and non-GHG preferences at the same time



Ignoring GHG, how would we set prices for the non-GHG area?



Ignoring GHG, how would we set prices for the non-GHG area?



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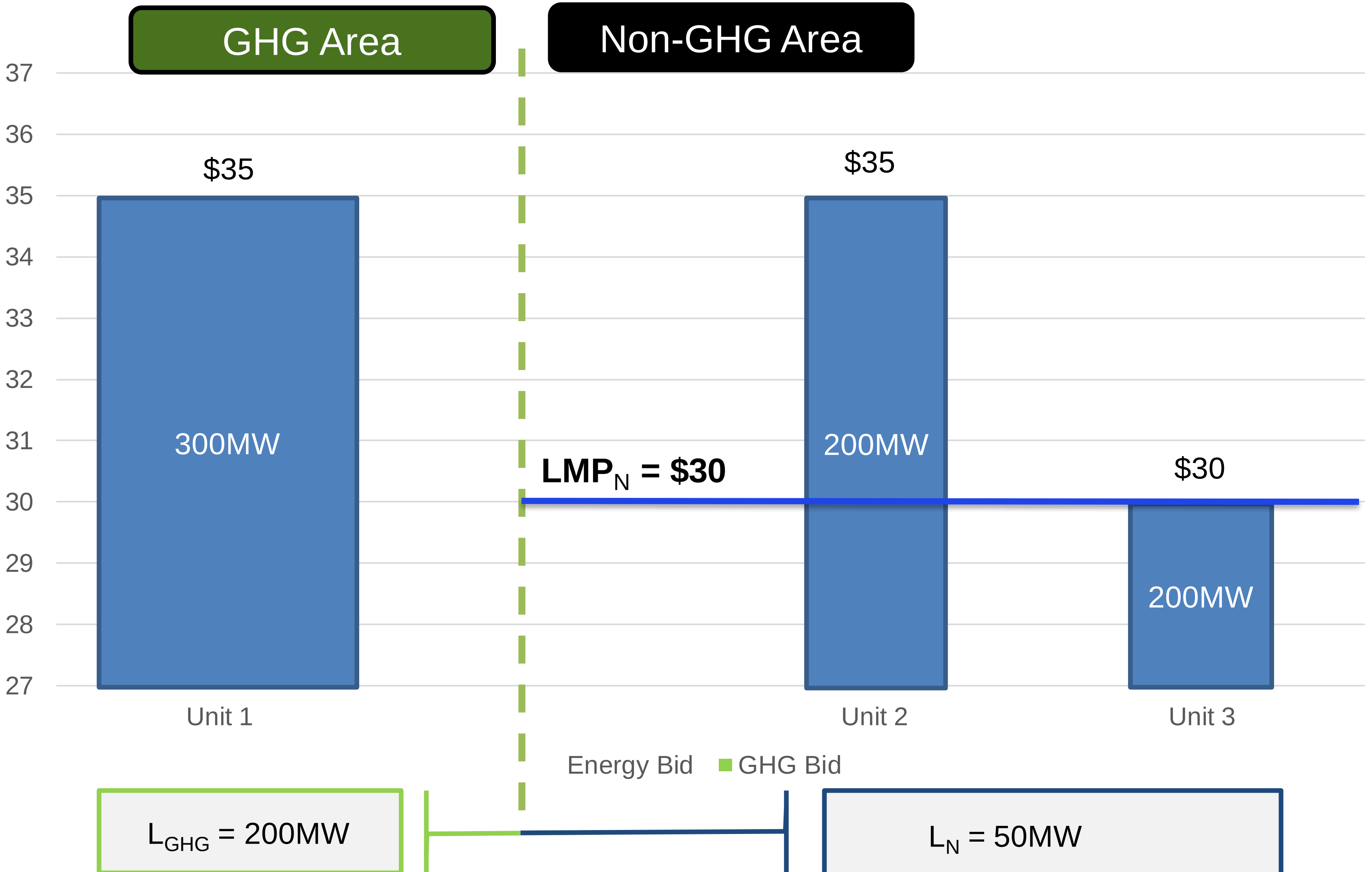
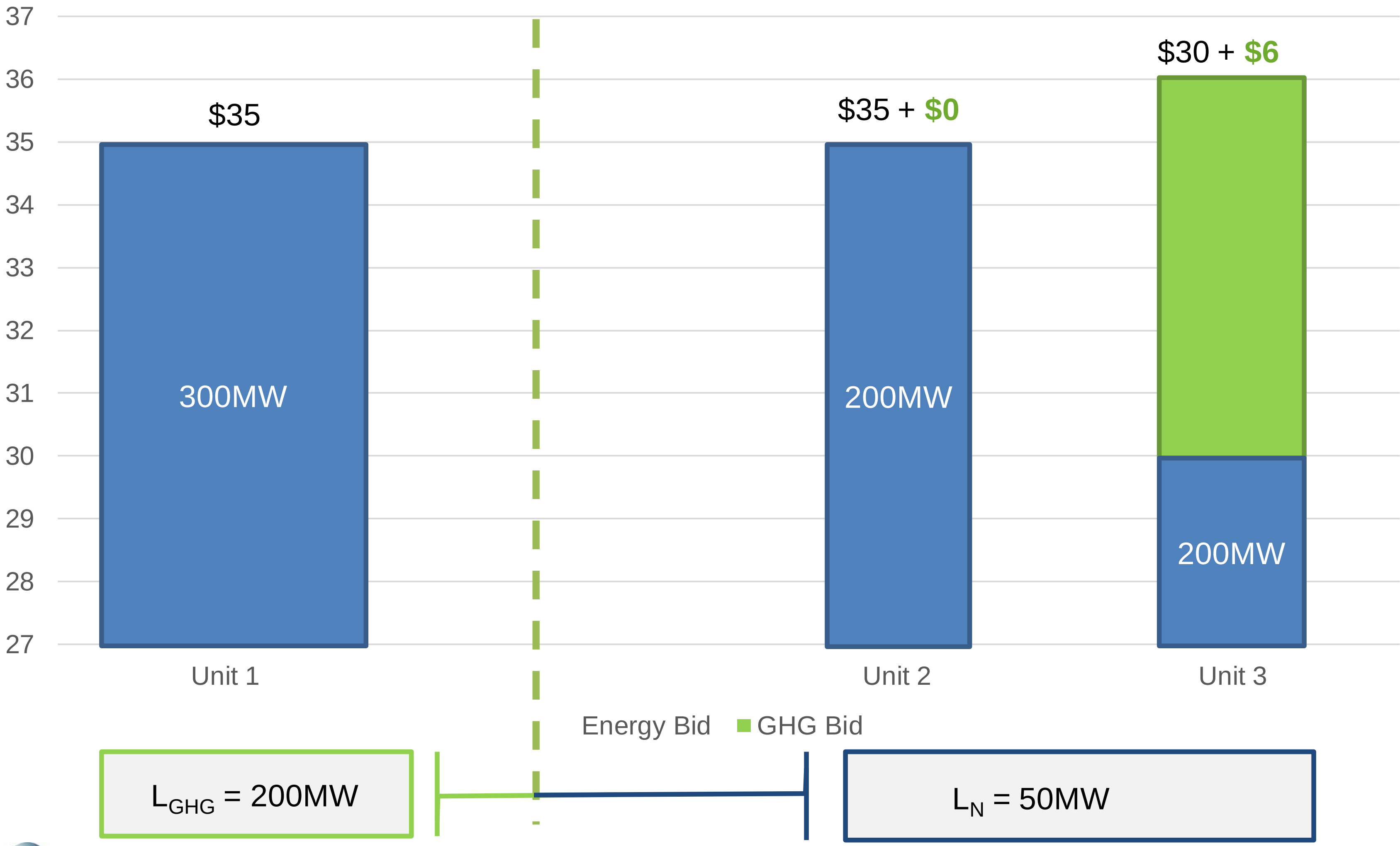
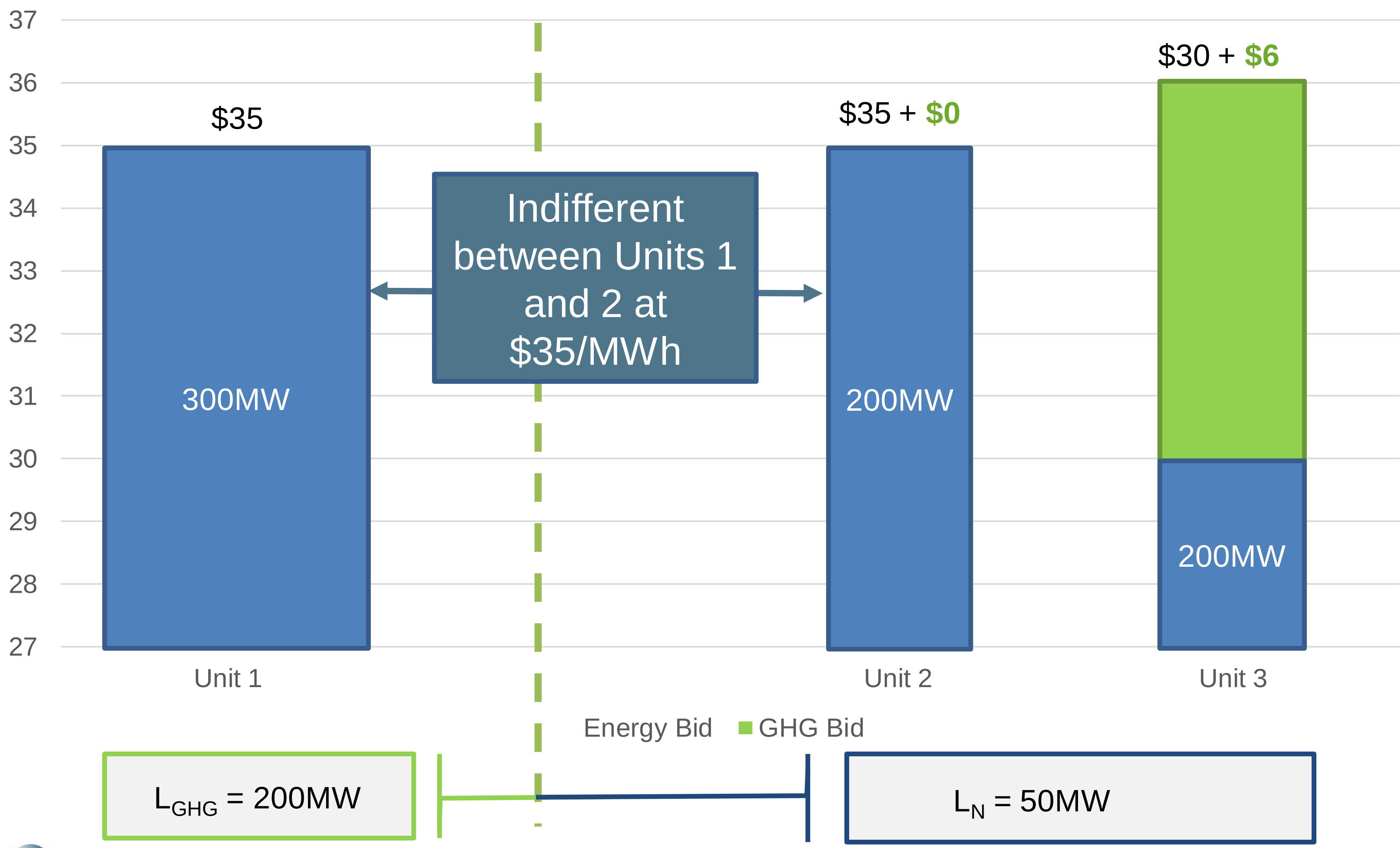


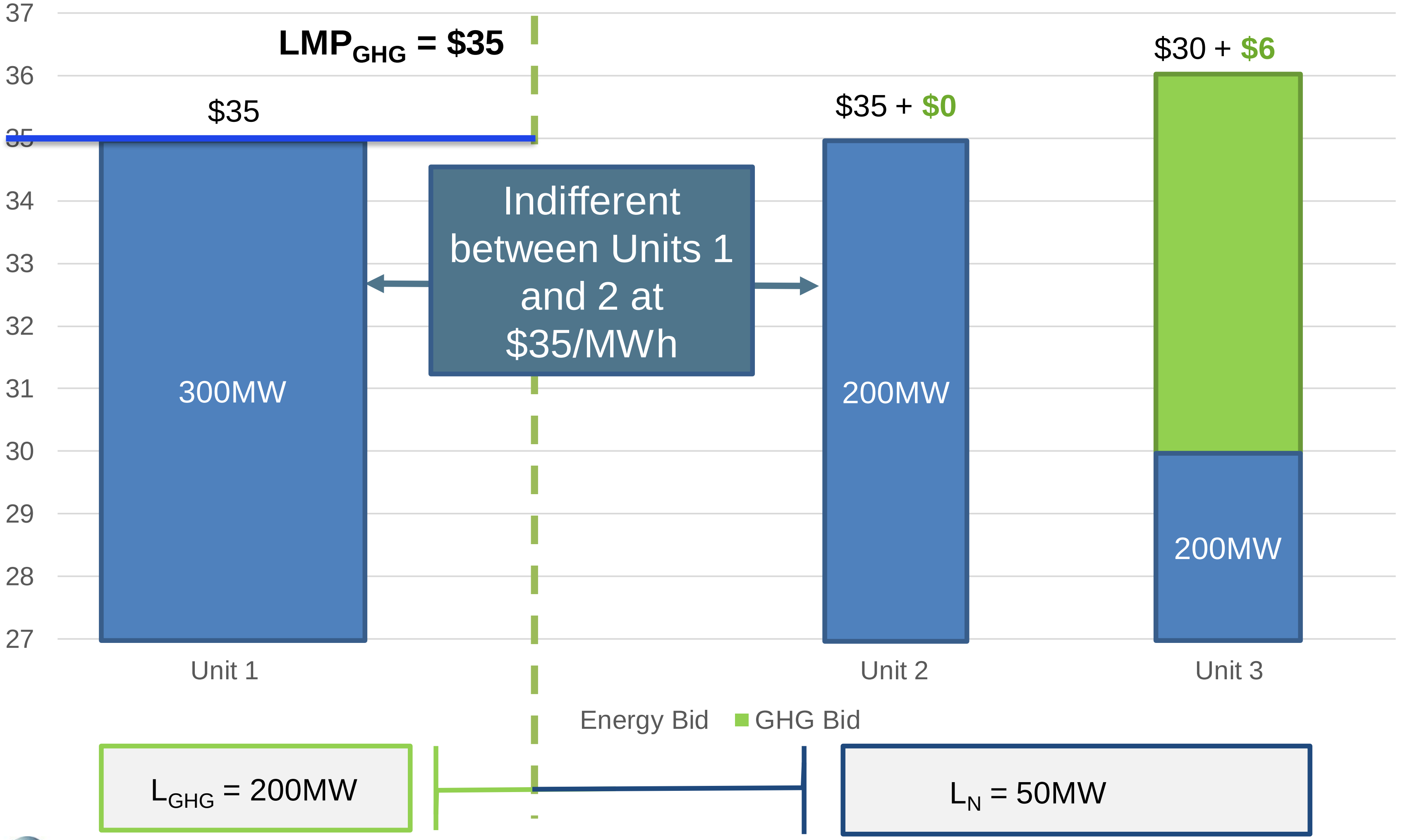
Accounting for GHG, how would we set prices for the GHG area?



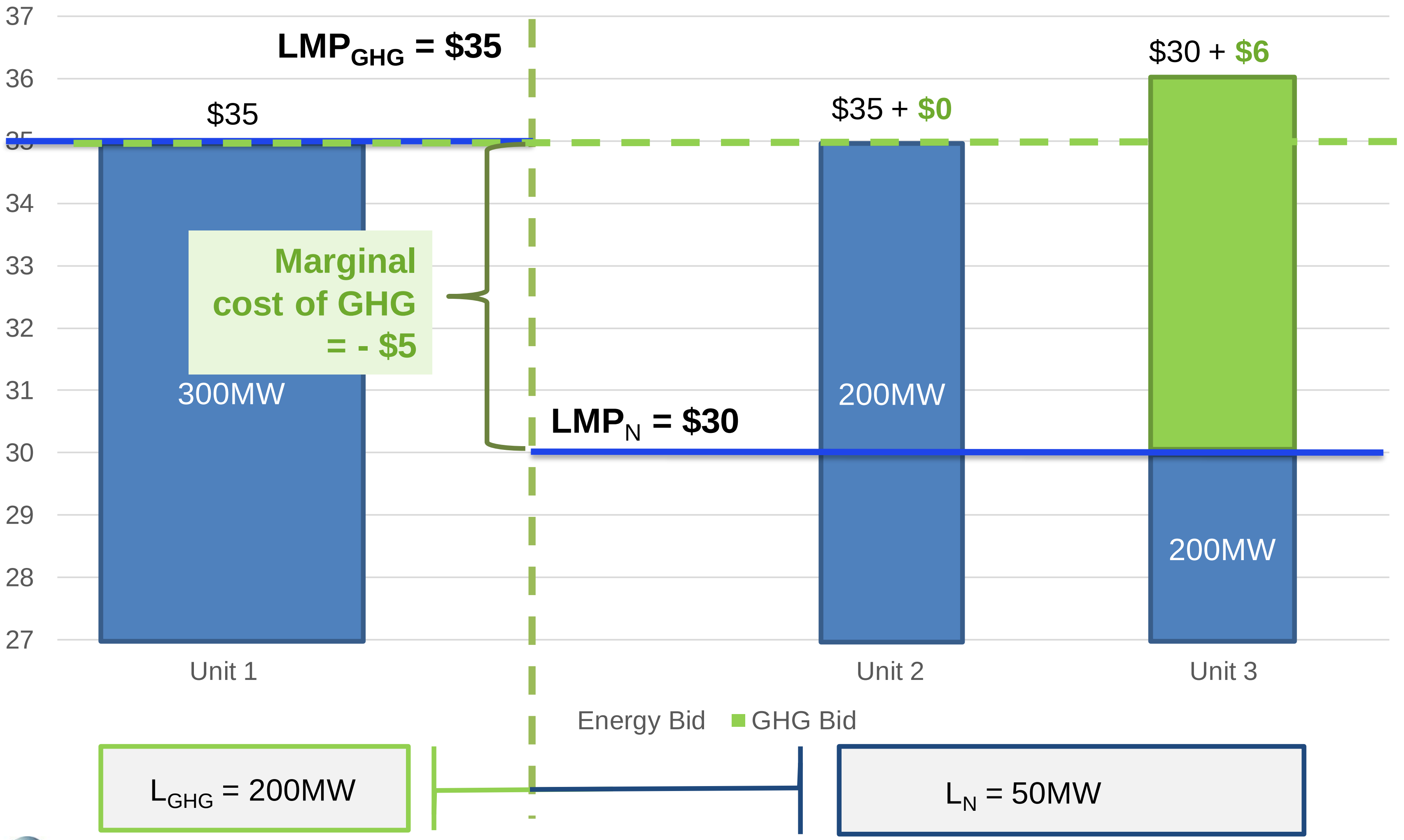
Accounting for GHG, how would we set prices for the GHG area?



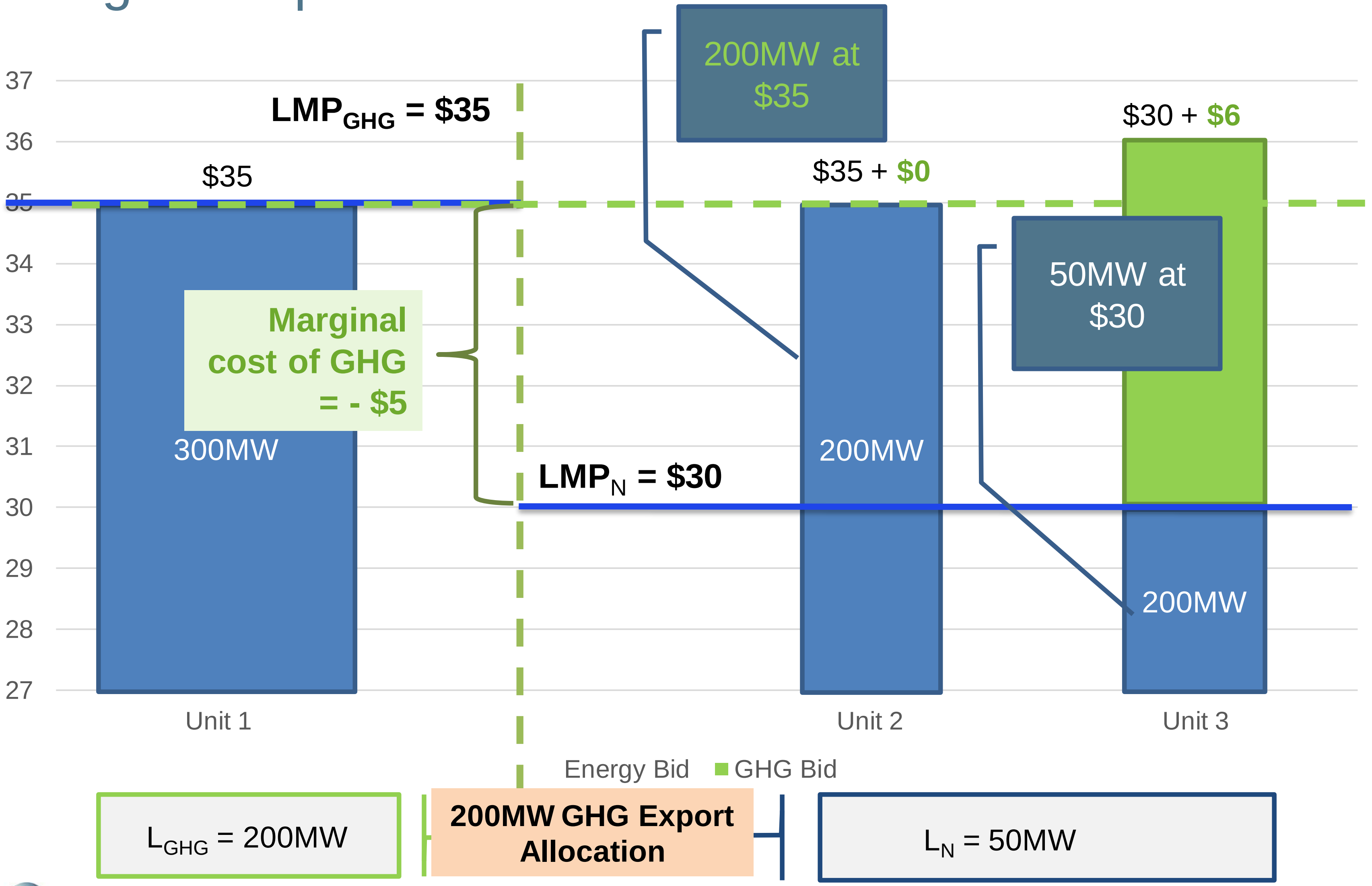
Accounting for GHG, how would we set prices for the GHG area?



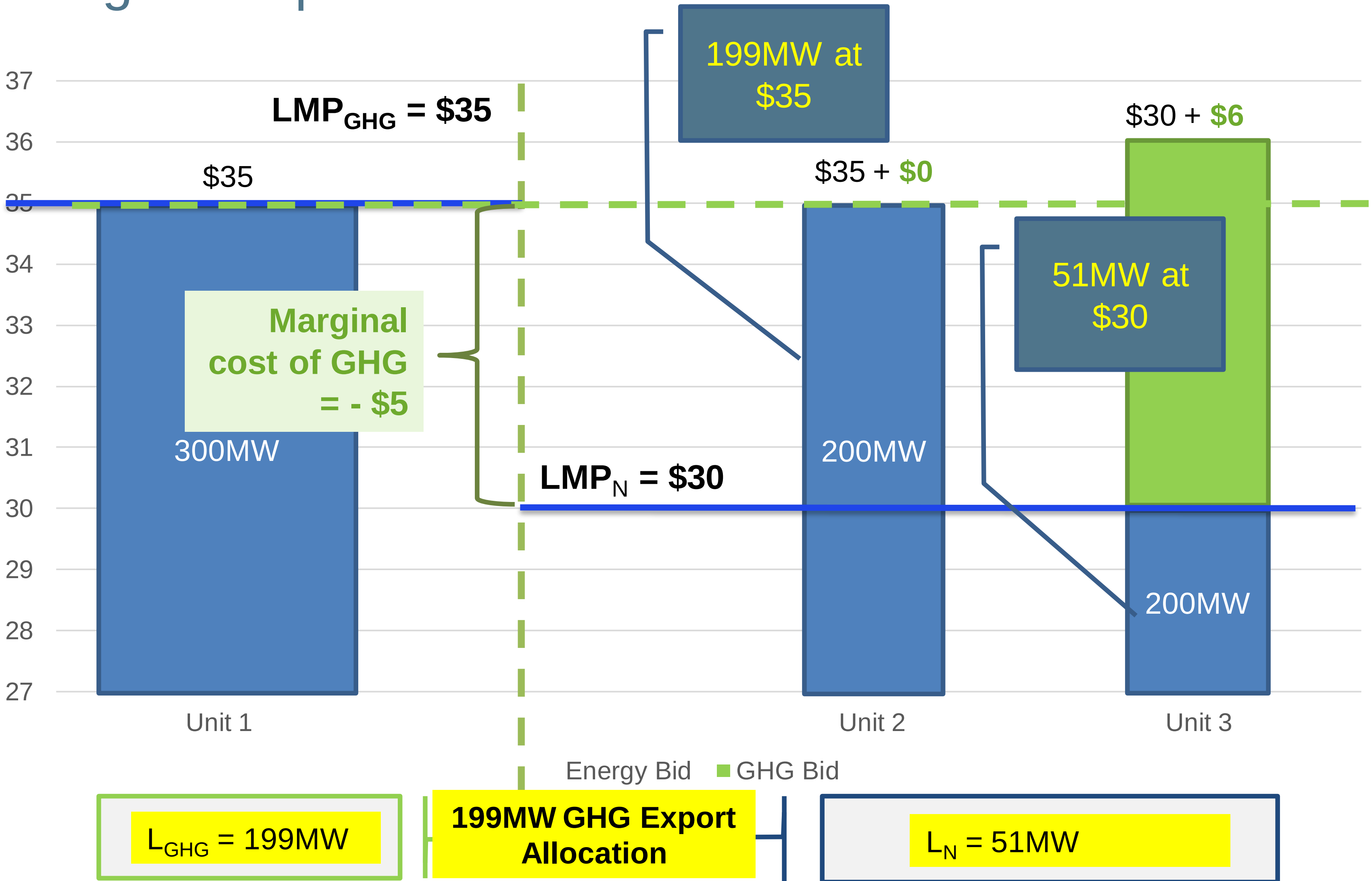
The marginal cost of GHG is the cost to the system of a marginal export to the GHG area



The marginal GHG cost is the cost to the system of a marginal export to the GHG area



The marginal GHG cost is the cost to the system of a marginal export to the GHG area



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Determining the MC-GHG

- The GHG export allocation carries the cost of GHG regulation, which can be a compliance cost or energy cost in excess of what the non-GHG area is willing to pay

- The MC-GHG can be verified if we relax the export allocation by 1MW
  - If we substitute 1MW of an export allocation for 1MW of capacity used to meet the non-GHG area, we can use 1MW of Unit 3 ($30) instead of 1MW from Unit 2 ($35)
  - This reduces the total cost of the system by $5/MWh

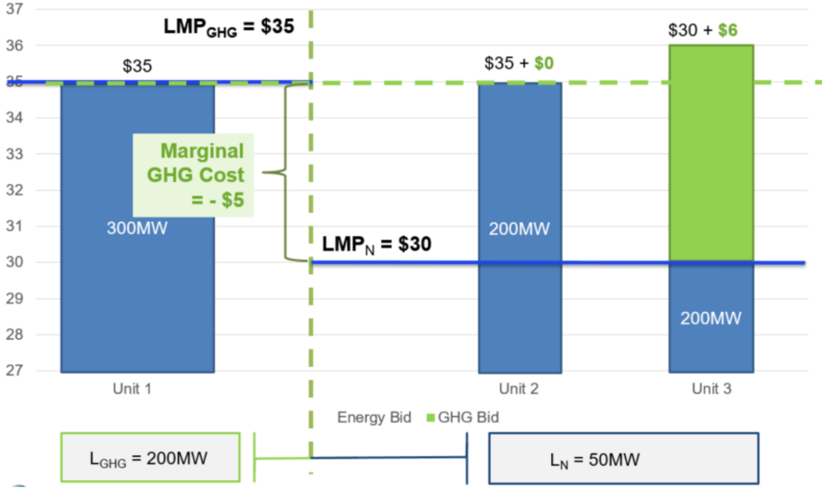
The sign today and sign tomorrow of the MC-GHG

- In this presentation, and in the market today, the MC-GHG shows up as a negative component of the LMP in the non-GHG area.

- In the ISO's Extended Day Ahead Market (EDAM), the MC-GHG will be reflected as a positive component in the GHG area.

- The sign change would not change the solution found in these examples, and will not have an effect on market outcomes.

GHG Export Allocation



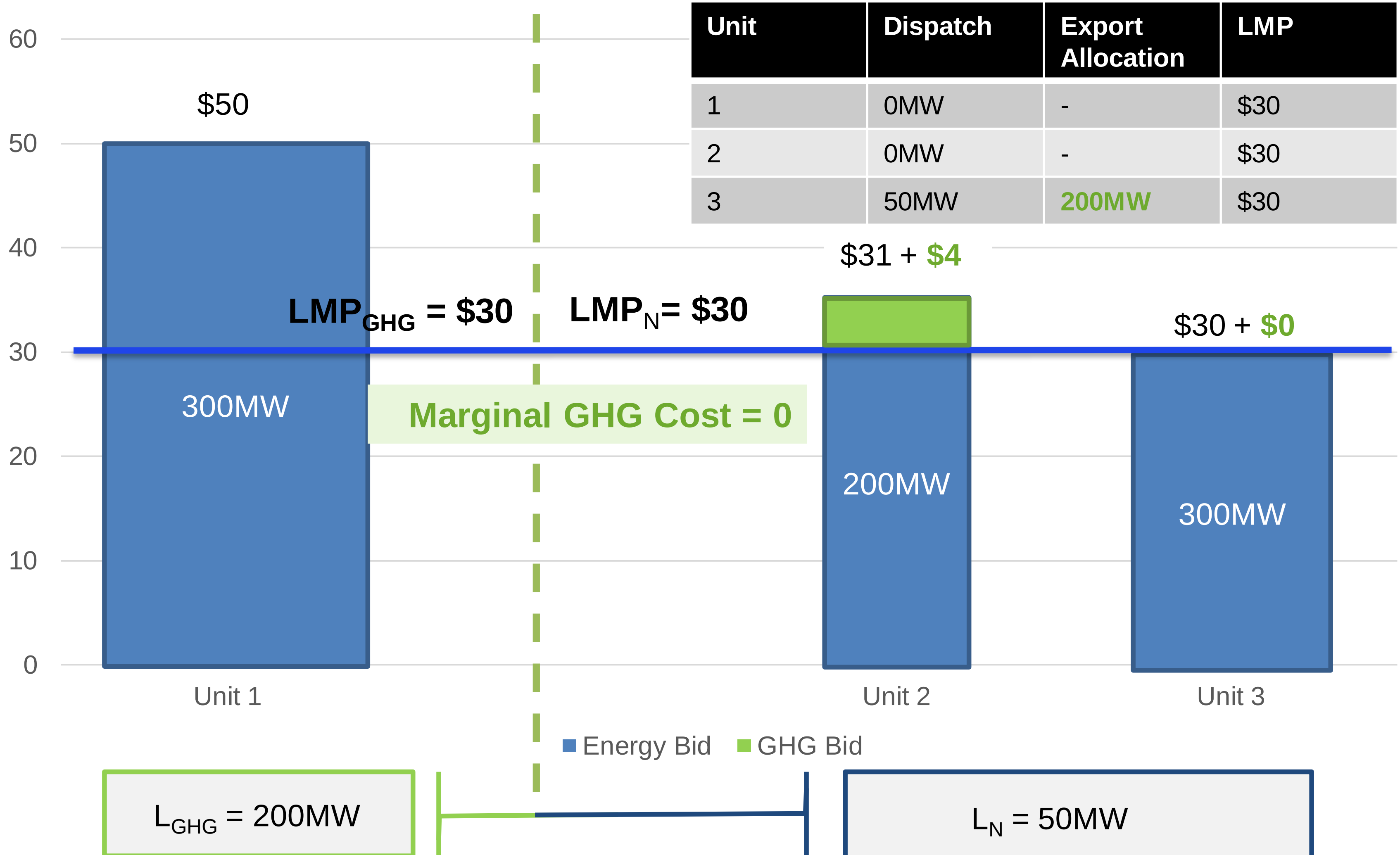
- In this example, we do not know the GHG export allocation (but also don't need to).
- This is a 'degenerate' solution, and is not typical.

- The marginal cost of GHG is a function of:
  - The GHG export allocation
  - The relative cost of resources eligible for attribution in the non-GHG area

- In chapter 4, a transmission constraint will help us calculate the GHG export allocation

A GHG export allocation may not impose an additional cost on the non-GHG area

Unit	Dispatch	Export Allocation	LMP
1	0MW	-	$30
2	0MW	-	$30
3	50MW	**200MW**	$30



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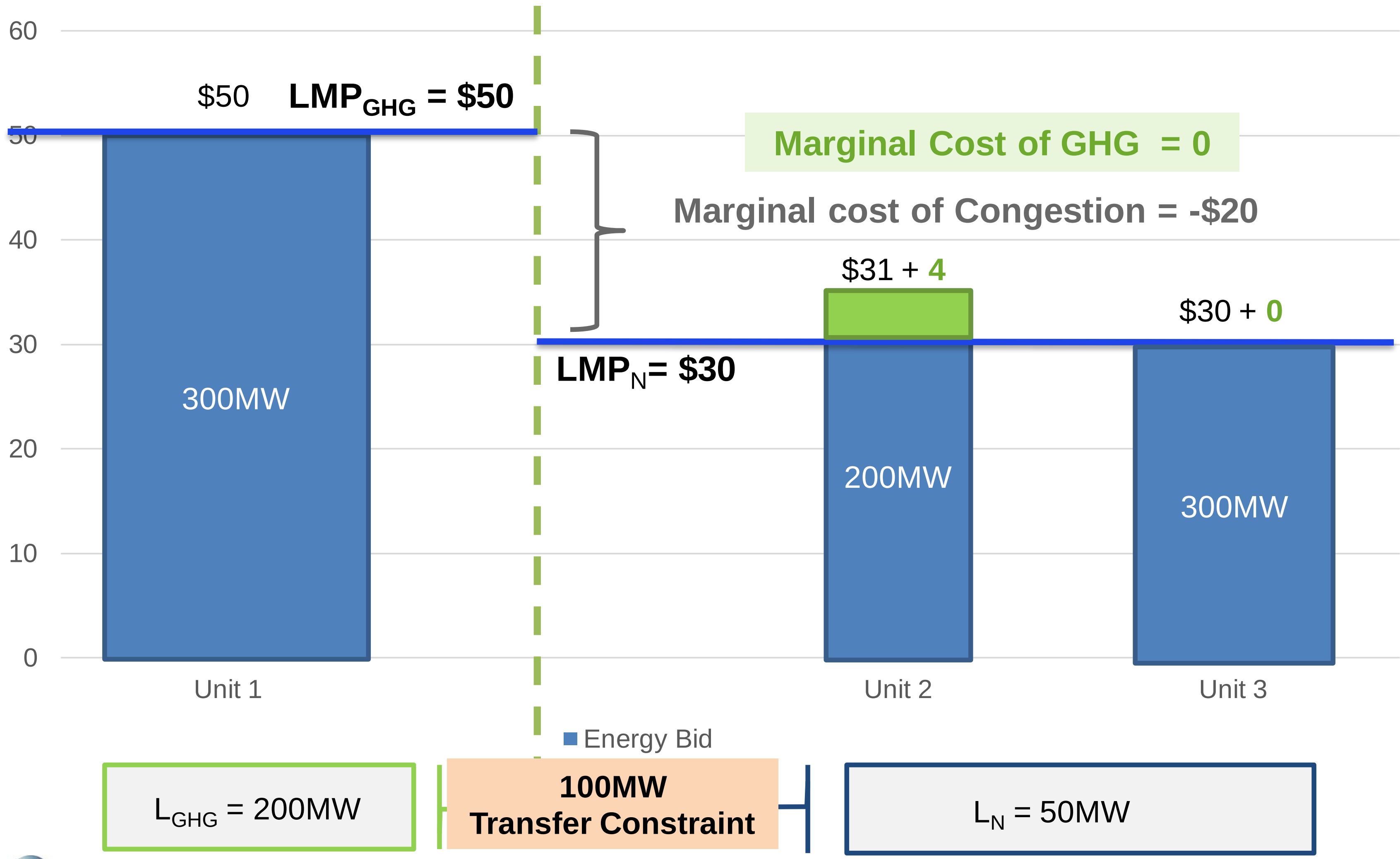
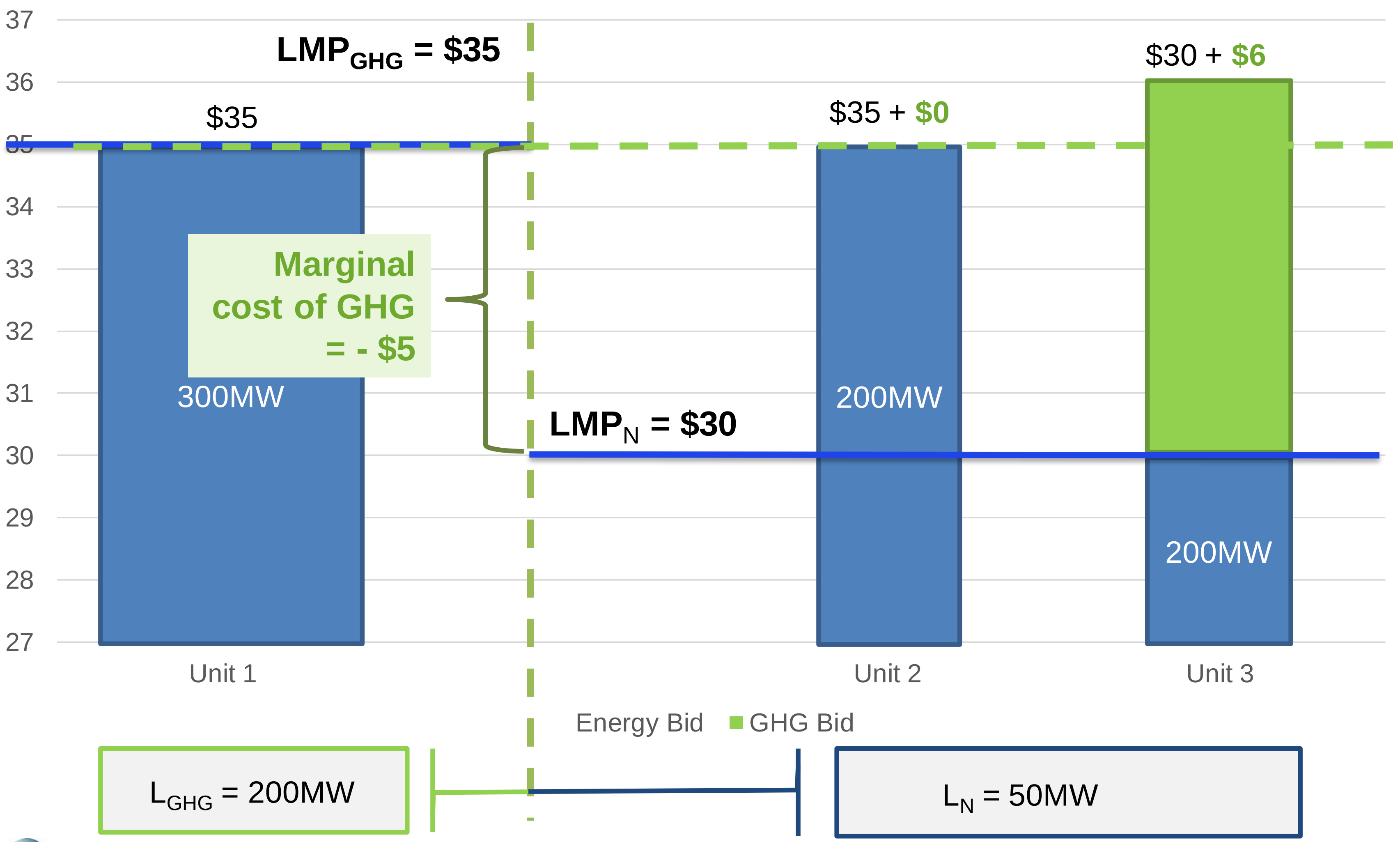
Congestion might account for a price difference

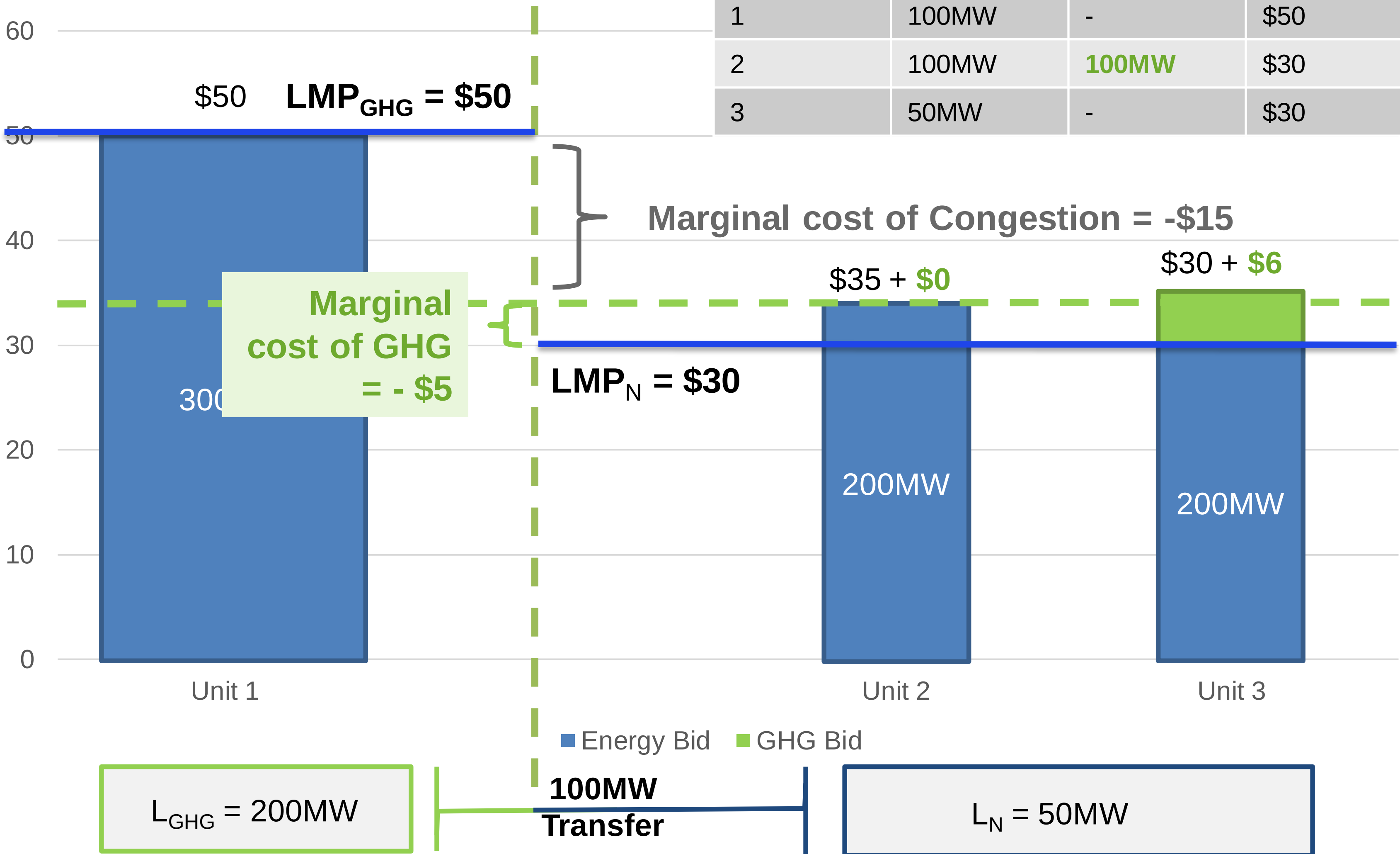


Putting it all together



Putting it all together

Unit	Dispatch	Export Allocation	LMP
1	100MW	-	$50
2	100MW	100MW	$30
3	50MW	-	$30



Takeaways

- The difference in LMPs between the two areas account for some combination of GHG and congestion costs.
- When there is no difference in LMPs, there may still be a transfer between areas. In this case, load in each area will still only pay for what load in that area is responsible for.
- Chapter 4 will break down how the costs are determined and allocated to load in each area.

Overview of GHG Price Formation Evergreen Training

Chapter 1: Background and Context

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Chapter 4

EXAMPLES OF PRICE FORMATION WITH GHG

Example Set Up

- All four of the examples in this section can be found in the BPM for the Energy Imbalance Market

- Section 11.3.3.2: Greenhouse Gas Methodology, contains
  – The mathematical formulation in the optimization, and
  – Examples

$$\min\left(\sum_i C_i\, G_i + \sum_j (C_j\, G_j + C_{Gj}\, E_j)\right)$$

subject to:

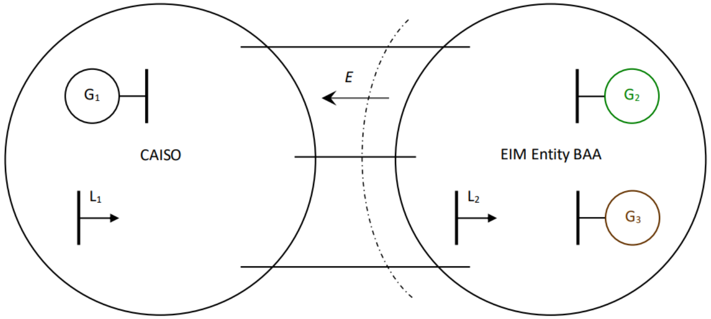
power balance: $\sum_i (G_i - L_i) + \sum_j (G_j - L_j) = 0$

transmission line flow: $F_k \equiv \sum_i S_{i,k}\,(G_i - L_i) + \sum_j S_{j,k}\,(G_j - L_j) \le F_{\mathrm{MAX}k}, \forall k$

net export allocation: $E \equiv \sum_j (G_j - L_j) \le \sum_j E_j$

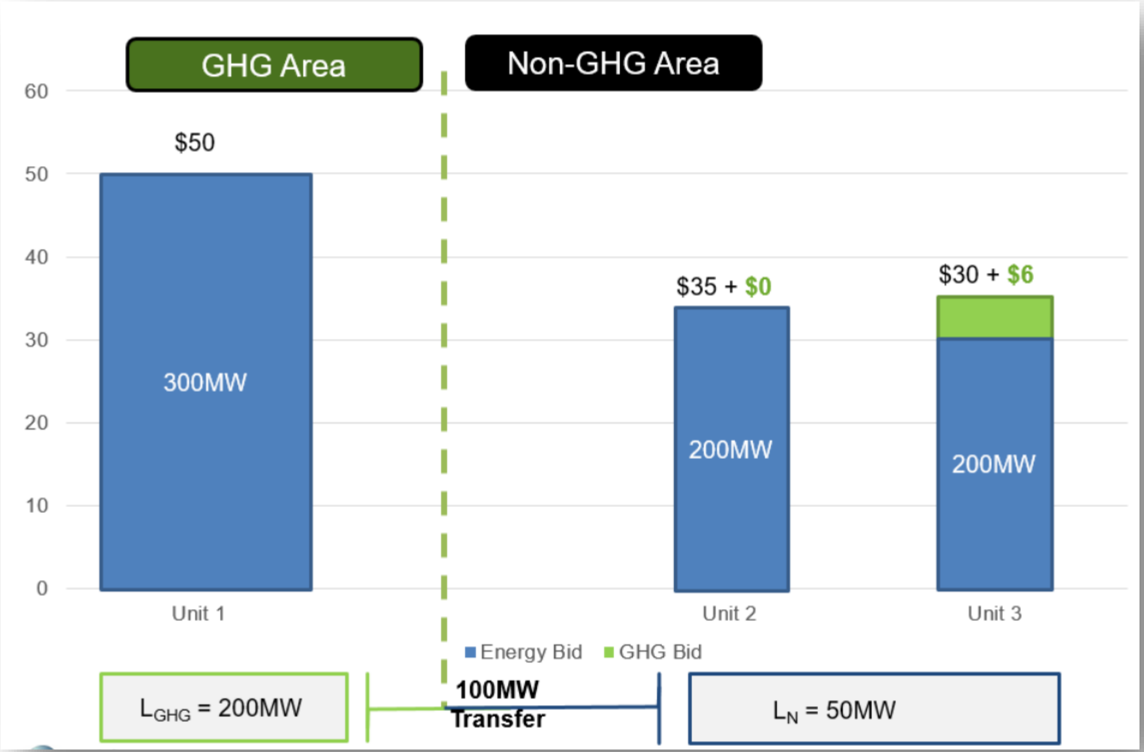
generator limits: $G_{\mathrm{MIN}i} \le G_i \le G_{\mathrm{MAX}i}, \forall i$
$G_{\mathrm{MIN}j} \le G_j \le G_{\mathrm{MAX}j}, \forall j$

allocation limits: $0 \le E_j \le \min(G_j, E_{\mathrm{MAX}j}), \forall j$



Example Set Up

The two areas included in these examples are labeled the GHG area and Non-GHG area:



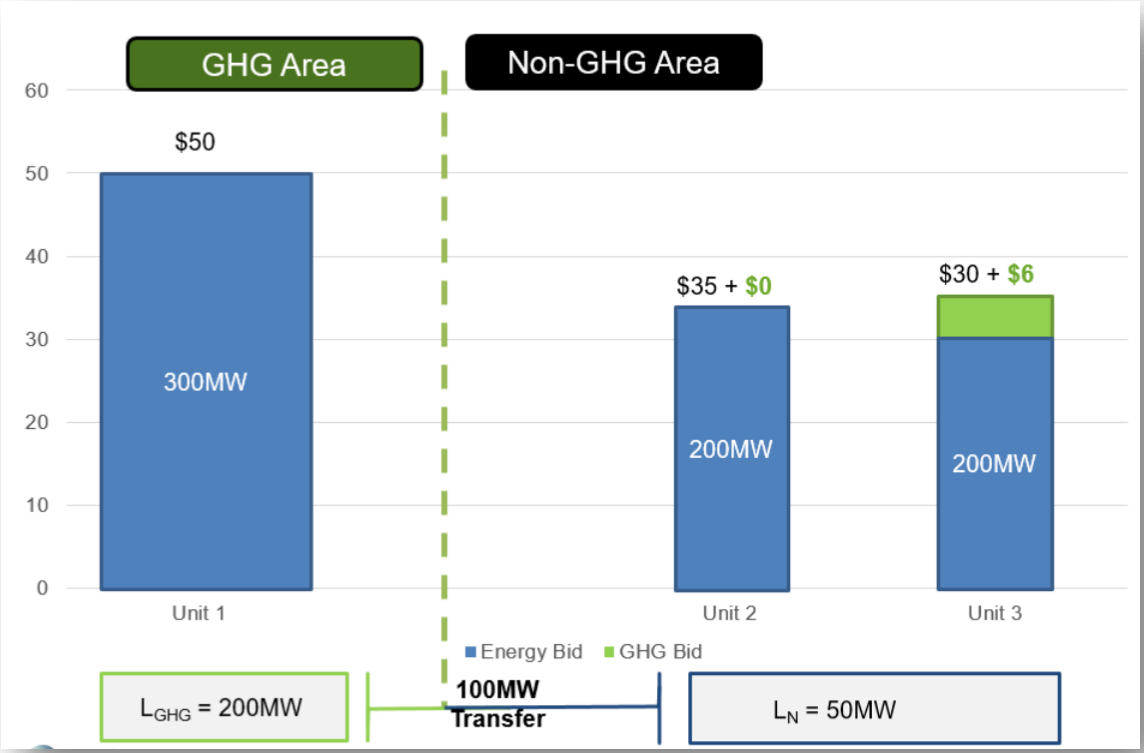
Each example will show a transfer constraint between the two areas. In the example above, only 100MW of Units 2 and 3 can be transferred to load in the GHG area.

Example Set Up

The GHG has load and 1 resource:

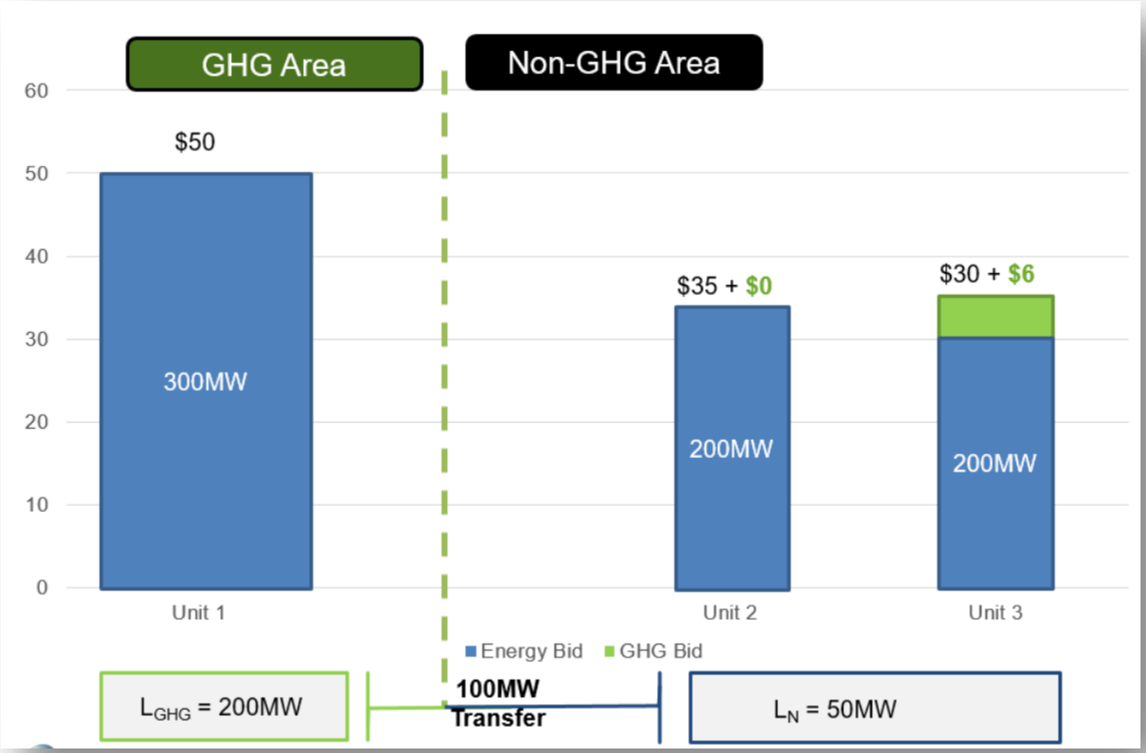
Load in the GHG area is L_{GHG}

The resource in the GHG area is Unit 1; **Unit 1 submits an energy bid only**, which is expected to include the cost of GHG compliance



Example Set Up

The non-GHG area has load and multiple resources:



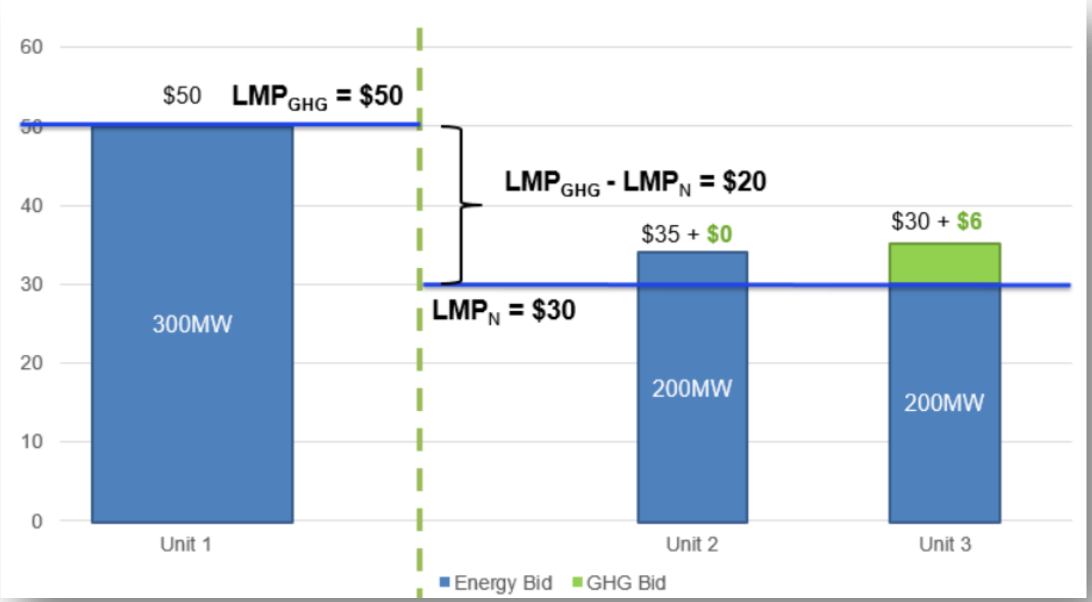
Load in the non-GHG area is L_N

Units 2 and 3 submit separate energy and GHG bids ($/MWh); Assume both units offer a GHG MWh bid for max capacity into the GHG area for all examples.

Example Set Up

Both areas have their own LMP: LMP_{GHG} and LMP_N

LMP_{GHG} is the price signal for the GHG area resource. Unit 1 is paid LMP_{GHG}.

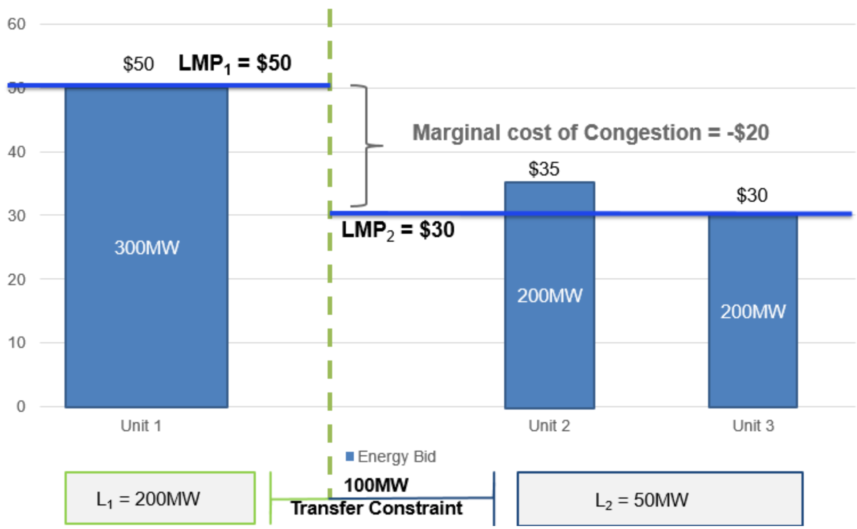


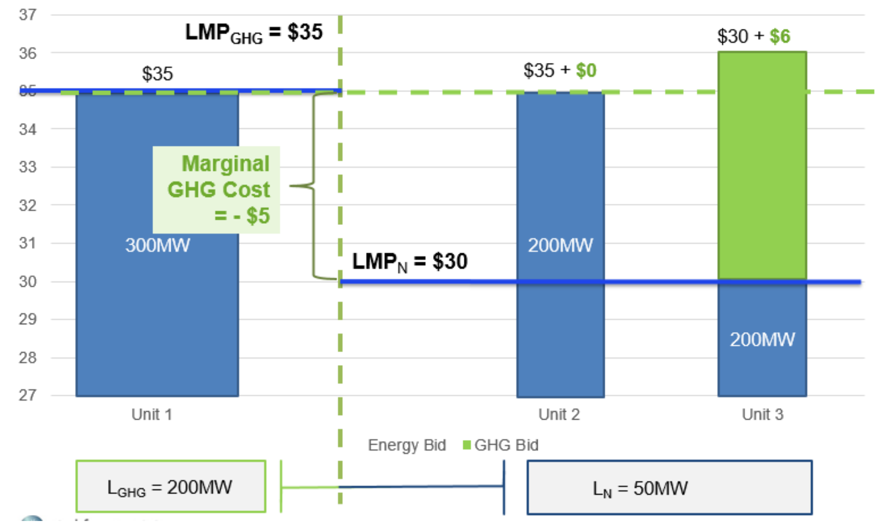
LMP_N is the price signal for the non-GHG area resources. These resources are paid LMP_N

In each example, the price separation between the GHG and non-GHG area LMPs can be accounted for through some combination of GHG and Congestion

Example Set Up

Both areas have their own LMP: LMP_{GHG} and LMP_N





In this example, the price difference comes from congestion only.

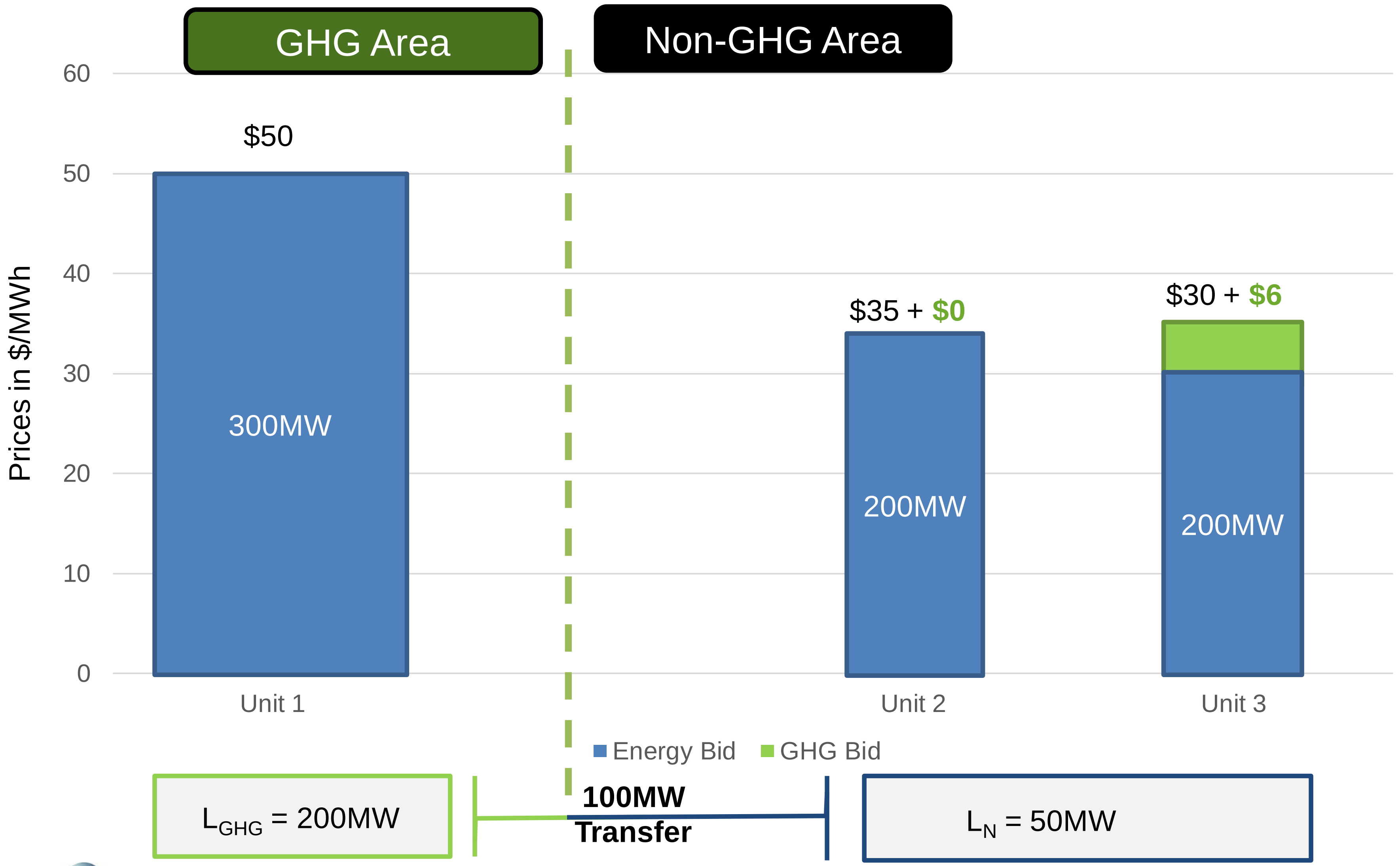
In this example, the price difference comes from the MC-GHG only. Only resources identified for transfer to the GHG area are paid this additional price signal.

Caveat

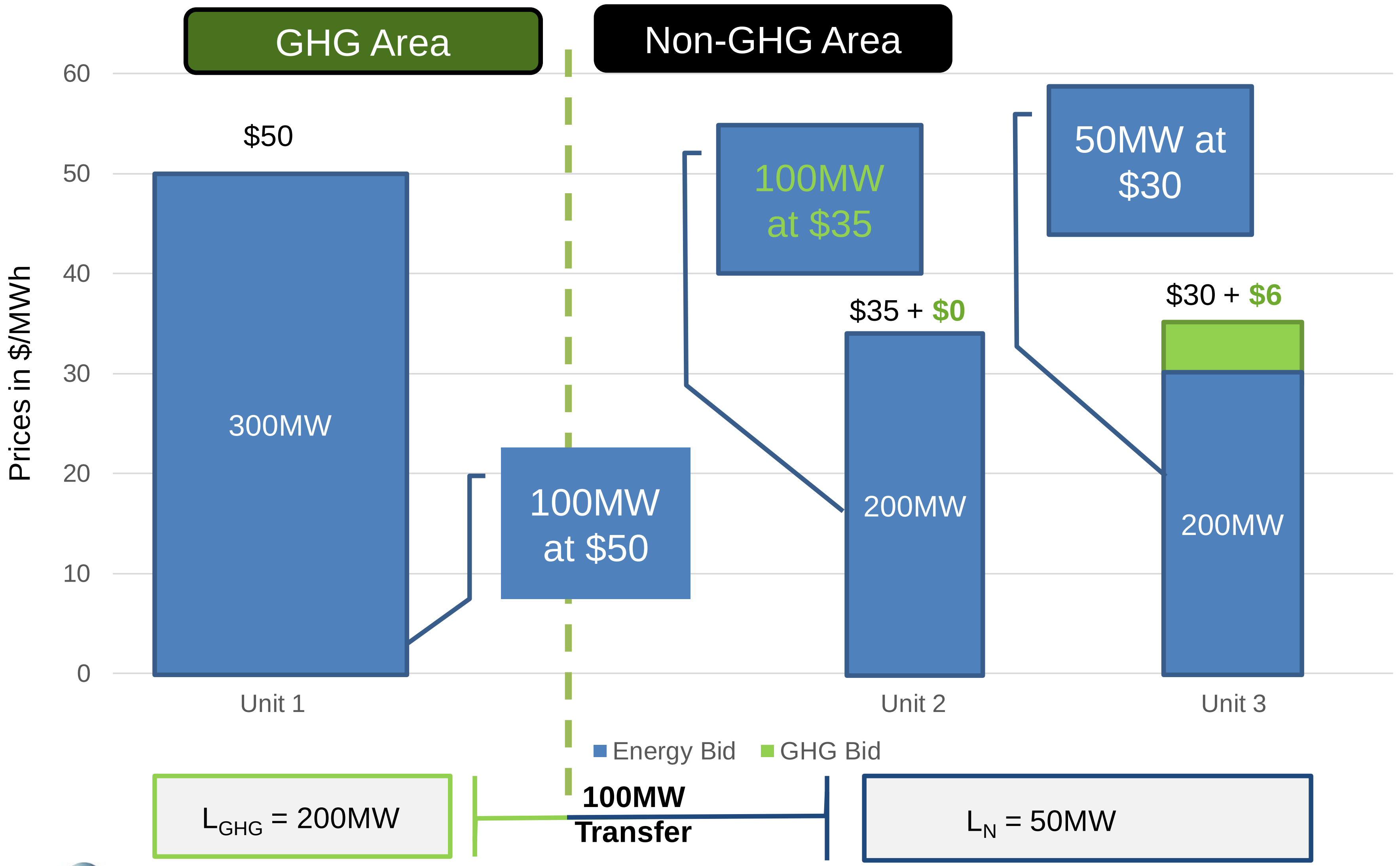
- This is a simplified example, intended to help build the intuition behind GHG accounting and the GHG market design policy.
- These examples do not illustrate additional aspects of GHG market design policy, i.e. constraints intended to limit secondary dispatch.
- What we see in a solver, or in market results, may differ because of increased complexity.

EXAMPLE 1

Example 1: How should we dispatch 250MW?

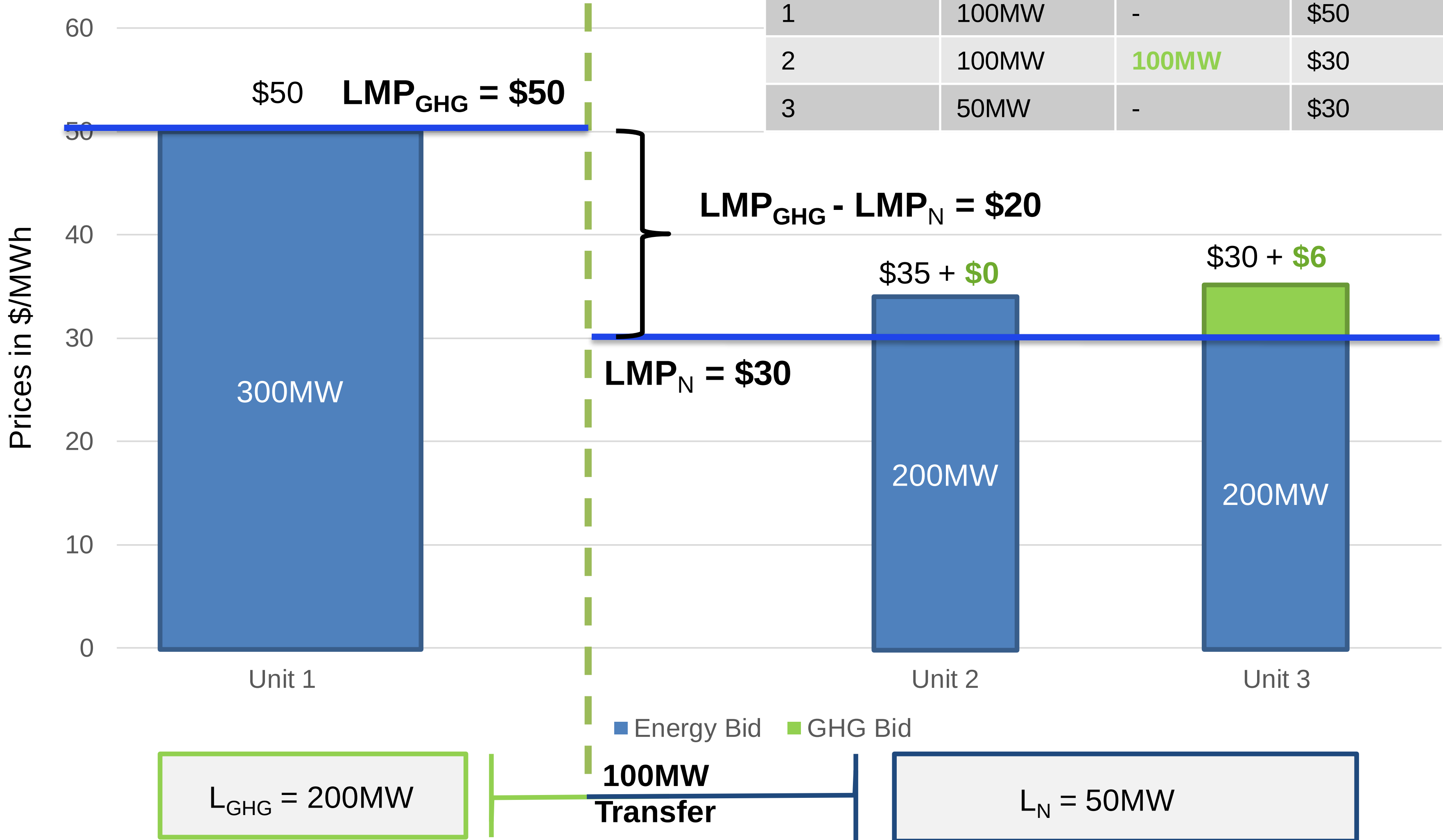


Example 1: How should we dispatch 250MW?



Example 1: How should we set prices?

Unit	Dispatch	Export Allocation	LMP
1	100MW	-	$50
2	100MW	100MW	$30
3	50MW	-	$30



Example 1: How should we set prices?

Unit	Dispatch	Export Allocation	LMP
1	100MW	-	$50
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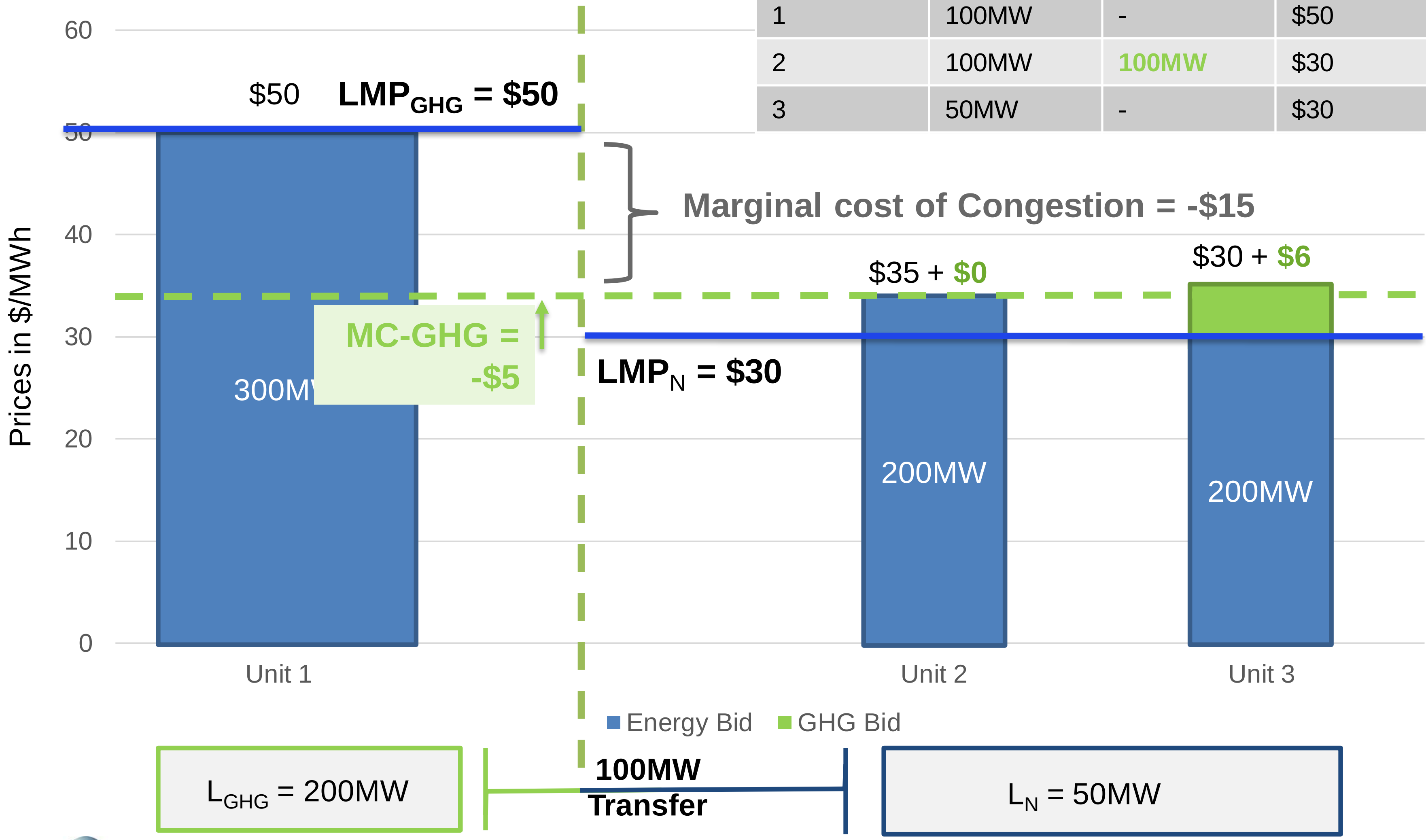
3	50MW	-	$30



Example 1: Summary of LMP breakdown

- LMP GHG = $50/MWh
- LMP non-GHG = $30/MWh

- Price difference between the GHG and non-GHG areas is $20/MWh, and made up by:
  - Marginal Congestion Cost = $15/MWh
  - Marginal GHG Cost = $5/MWh

- A 100MW export allocation generates:
  - Congestion revenue = $1,500
  - GHG revenue = $500 allocated to Unit 2

Example 1: The price in the GHG area, and the MC-GHG, are price signals for resources serving L_{GHG}

Unit	Dispatch (MW)	GHG Export Allocation (MW)	Energy Bid (+ Compliance) ($)	LMP_{GHG} ($/MWh)	LMP_N ($/MWh) + MC-GHG
1	100	-	50	50	-
2	100	100	35	-	35
3	50	-	36	-	35
Total	250	**100**			

Unit 1 is paid LMP_{GHG} at $50/MWh. Unit 1 includes compliance in it's bid already, which is $50/MWh.

In the non-GHG area, the price signal for resources serving the GHG area is $35: LMP_N ($30) plus the MC-GHG ($5).

The market considers the total bid cost, including compliance, for resources serving the GHG area:

- **Unit 2** is economic to serve L_{GHG} at $35/MWh
- **Unit 3** is not economic to serve L_{GHG} at $36/MWh

Example 1: The price in the non-GHG area is the price signal for resources serving L_N

Unit	Dispatch (MW)	Energy Bid ($)	LMP_N ($/MWh)	Total Energy Cost ($)	Total Payment from LMP_N ($)	Excess Energy Payment ($)
1	100	50	-	5,000	-	-
2	100	35	30	3,500	3,000	(500)
3	50	30	30	1,500	1,500	0
Total	250			**10,000**	**9,500**	

The LMP_N is $30/MWh.

Unit 2 is not economic to serve L_N. LMP_N alone does not provide an incentive for this resource to dispatch. For each MW dispatched, Unit 2 would loose $5/MWh without an additional price signal.

Unit 3 is paid LMP_N which is sufficient to cover the marginal cost of capacity from this resource.

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Example 1: All export allocations receive a GHG payment for that export allocation

Unit	Dispatch (MW)	GHG Export Allocation (MW)	MC-GHG ($/MW)	GHG Payment ($)	GHG Adder ($/MWh)	GHG Compliance Cost ($)	Payment in excess of compliance ($)
1	100	-	-	-	-	-	
2	100	100	5	500	0	0	500
3	50	-	5	-	6	-	-
Total	250	**100**					

*GHG Export Allocation (MW) * MC-GHG = GHG payment*

Unit 2 costs $35/MWh and is economic to serve L_{GHG} only. The combined price signal, LMP_N + MC-GHG, sends the right signal for this resource. **The GHG revenue funded by the MC-GHG in this example is used to make this resource whole.**

Example 1: The GHG payment is sufficient to cover excess energy costs

Unit	Dispatch (MW)	Total Energy Cost ($)	GHG Compliance Cost ($)	Total Cost ($)	Excess Energy Payment ($)	GHG Payment ($)	Total Payment ($)
1	100	5,000	-	5,000	0	-	5,000
2	100	3,500	0	3,500	(500)	500	3,500
3	50	1,500	-	1,500	0	150	1,500
Total	250						

- LMP_N was insufficient to cover the full energy cost of Unit 2
  - Unit 2 does not have a GHG compliance cost, but is only economic to serve the GHG area

- The GHG payment, funded by $L_{GHG,}$ ensures the energy costs of Unit 2 are fully covered.

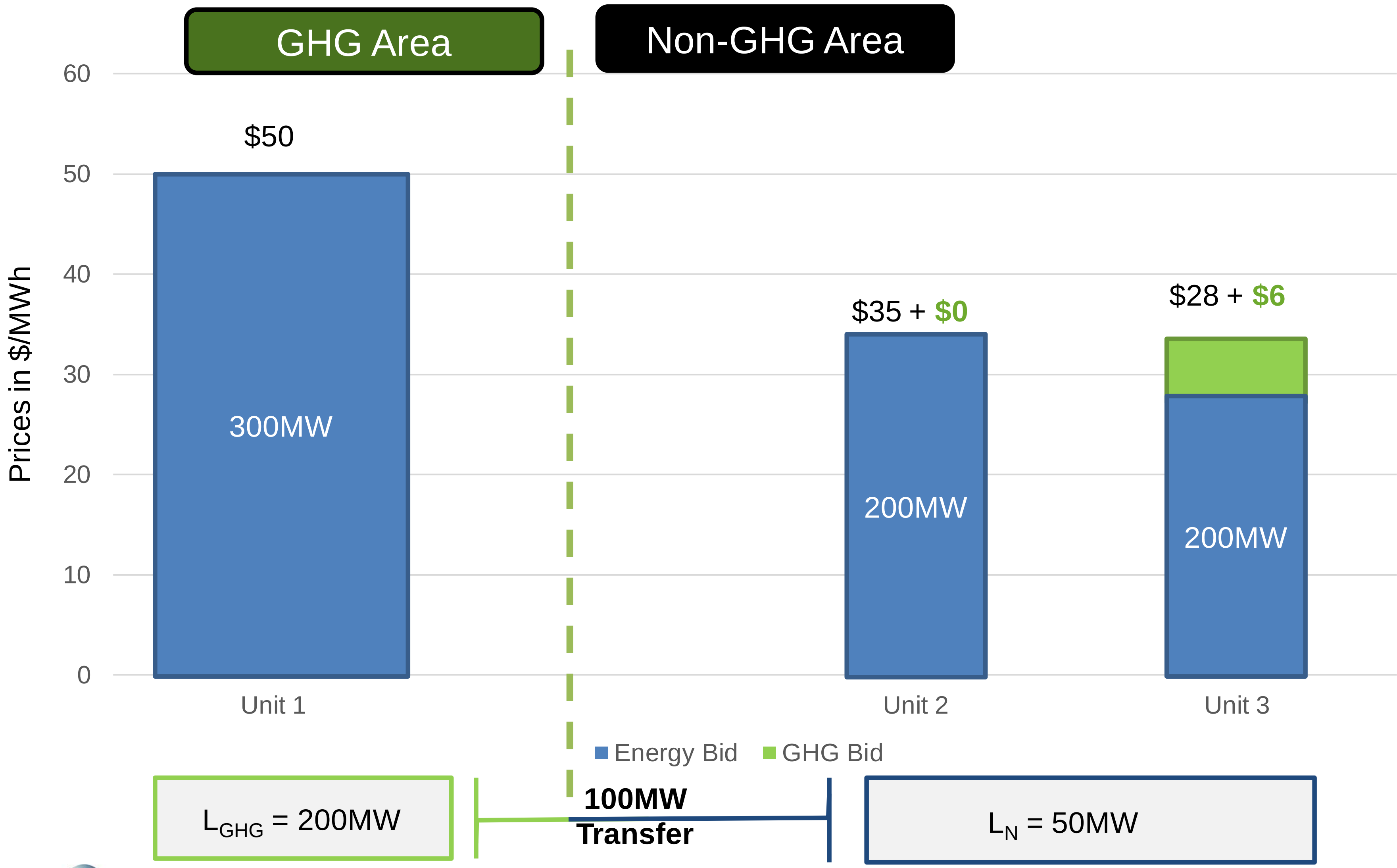
Example 1: Revenue funded by load in each area covers costs that load is responsible for

	Total Cost of Unit 1 ($)	Total Cost of Unit 2 ($)	Total Cost of Unit 3 ($)	Congestion Revenue	Load (MW)	LMP ($/MWh)	Total Payment funded by load ($)
L_{GHG}	5,000	3,500	-	1,500	200	50	10,000
L_N	-	-	1,500		50	30	1,500
Total	5,000	3,500	1,500	1,500			**11,500**

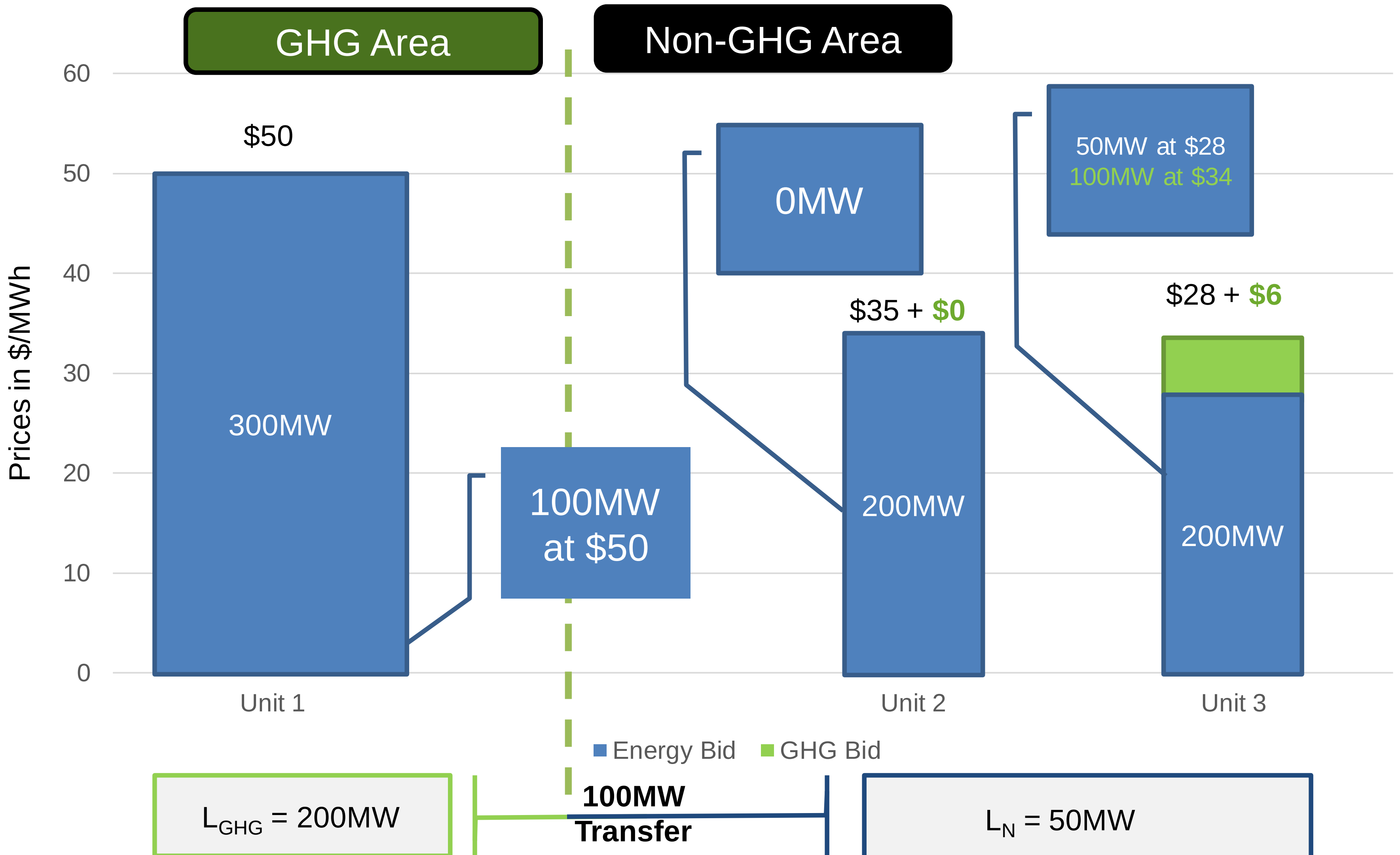
- $L_{GHG,}$ pays for the total cost of Units 1 and 2, and funds congestion revenue.
- L_N pays for the cost of Unit 3 only.

EXAMPLE 2

Example 2: How should we dispatch 250MW?

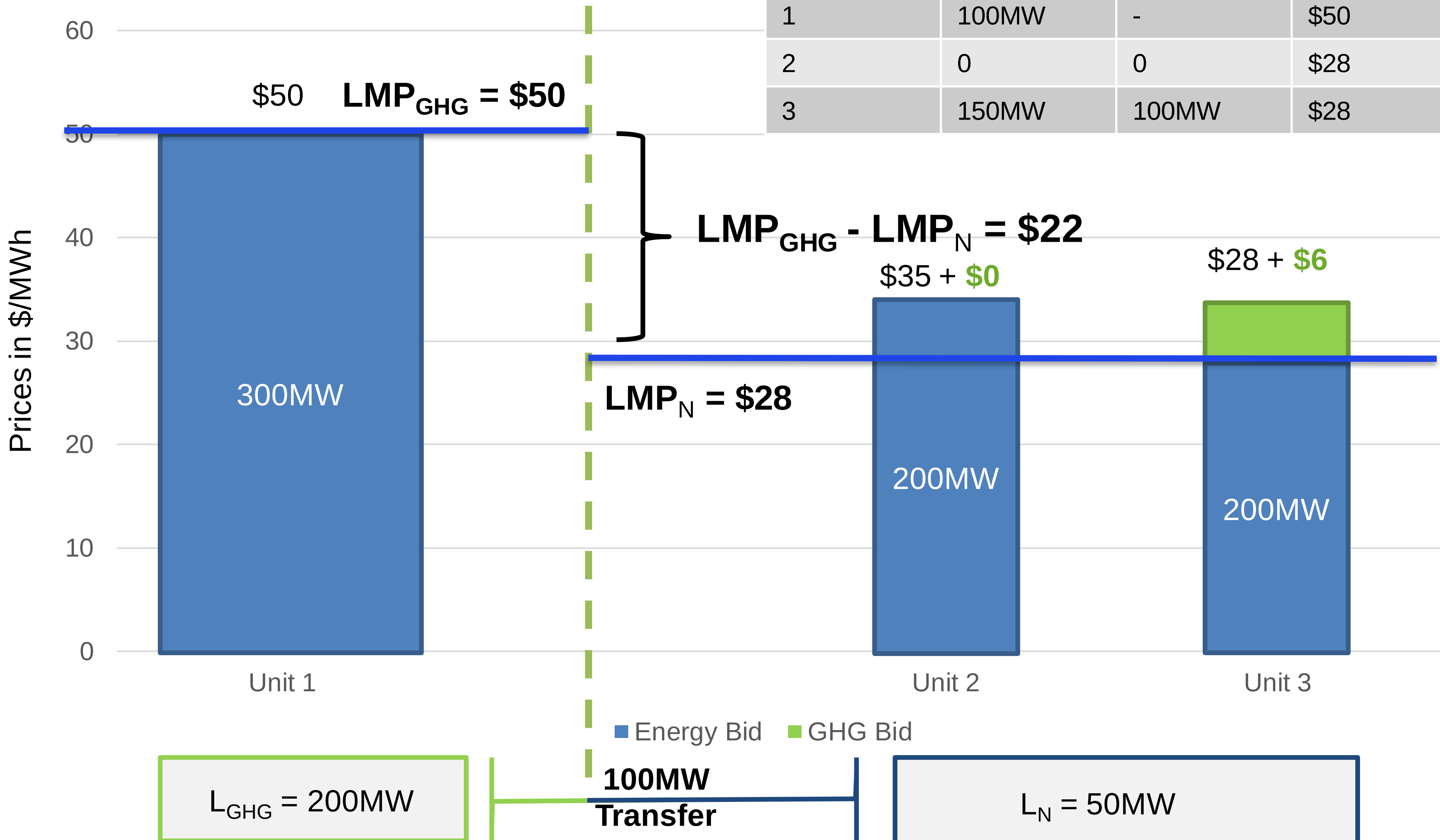


Example 2: How should we dispatch 250MW?



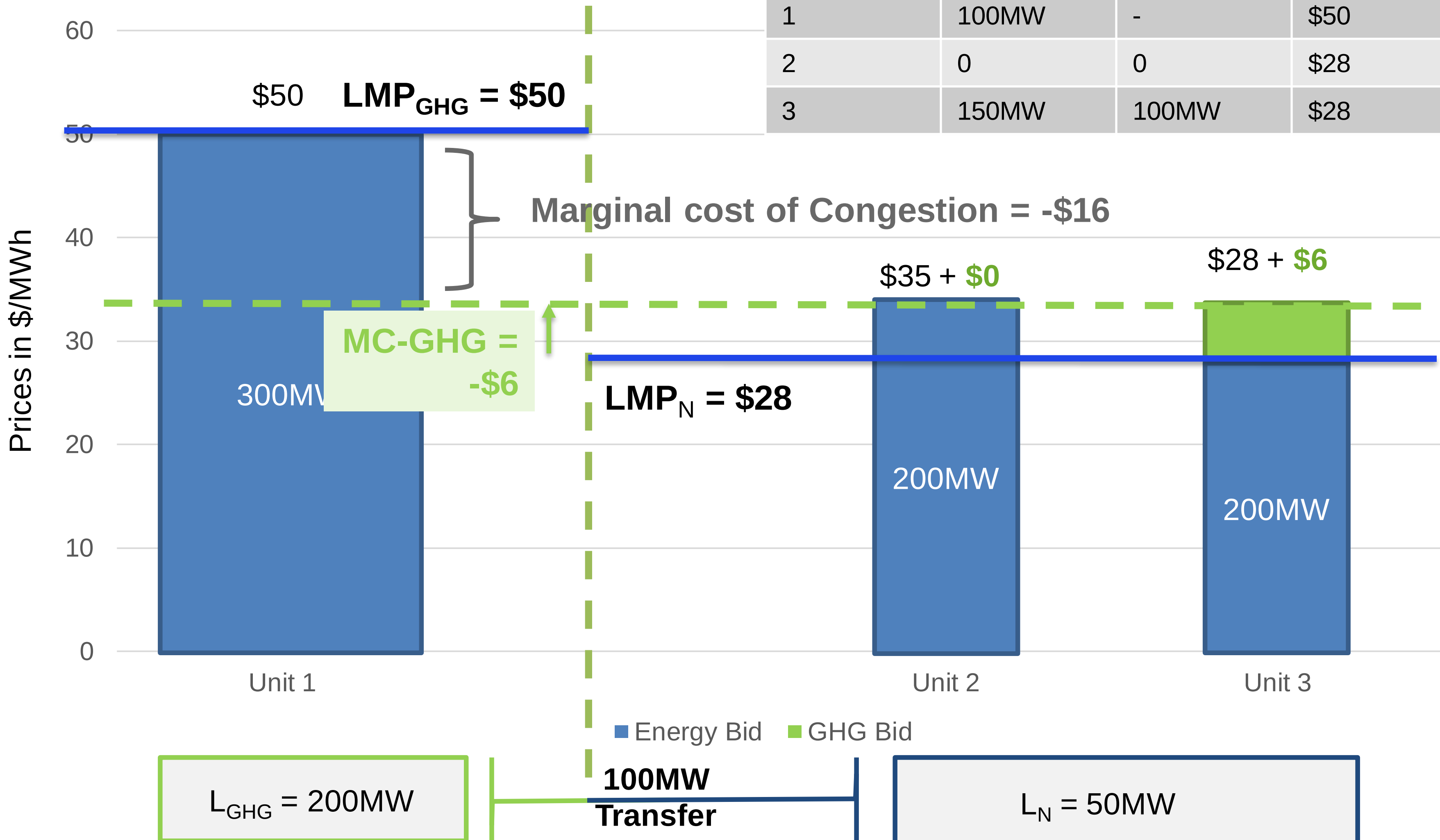
Example 2: How do we set prices?

Unit	Dispatch	Export Allocation	LMP
1	100MW	-	$50
2	0	0	$28
3	150MW	100MW	$28



Example 2: How do we set prices?

Unit	Dispatch	Export Allocation	LMP
1	100MW	-	$50
2	0	0	$28
3	150MW	100MW	$28



Example 2: Summary of LMP breakdown

- LMP GHG = $50/MWh
- LMP non-GHG = $28/MWh

- Price difference between the GHG and non-GHG areas is $22/MWh, and made up by:
  - Marginal Congestion Cost = $16/MWh
  - Marginal GHG Cost = $6/MWh

- A 100MW export allocation generates:
  - Congestion revenue = $1,600
  - GHG revenue = $600 allocated to Unit 3

Example 2: The price in the GHG area, and the MC-GHG, are price signals for resources serving L_{GHG}

Unit	Dispatch (MW)	GHG Export Allocation (MW)	Energy Bid (+ Compliance) ($)	LMP_{GHG} ($/MWh)	LMP_N ($/MWh) + MC-GHG
1	100	-	50	50	-
2	-	-	35	-	34
3	150	100	34	-	34
Total	250	**100**			

In the non-GHG area, the price signal for resources serving the GHG area is $34: LMP_N ($28) plus the MC-GHG ($6).

The market considers the total bid cost, including compliance, for resources serving the GHG area:

- **Unit 2** is not economic to serve L_{GHG} at $35/MWh
- **Unit 3** is economic to serve L_{GHG} at $34

Example 2: The price in the non-GHG area is the price signal for resources serving L_N

Unit	Dispatch (MW)	Energy Bid ($)	LMP_N ($/MWh)	Total Energy Cost ($)	Total Payment from LMP_N ($)	Excess Energy Payment ($)
1	100	50	-	5,000	-	-
2	-	35	28	-	-	-
3	150	28	28	4,200	4,200	0
Total	250			**9,200**	**4,200**	**0**

Unit 2 is not economic to serve L_N (or L_{GHG}).

Unit 3 is paid LMP_N. This resource is indifferent to dispatching capacity across it's operational range, which covers 50MW capacity for L_N and 100MW capacity for L_{GHG}.

- Revenue funded by L_N will be used to cover only the 50MW capacity the non-GHG area is responsible for.

Example 2: All export allocations receive a GHG payment for that export allocation

Unit	Dispatch (MW)	GHG Export Allocation (MW)	MC-GHG ($/MW)	GHG Payment ($)	GHG Adder ($/MWh)	GHG Compliance Cost ($)	Payment in excess of compliance ($)
1	100	-	-	-	-	-	
2	-	-	6	-	0	-	-
3	150	100	6	600	6	600	0
Total	250	**100**					

In this example, Unit 3 has a compliance cost which is covered by the GHG payment. In Example 1, the GHG payment was covered energy costs in excess of what the non-GHG area was willing to cover.

- GHG payment, a function of the export allocation and MC-GHG, is used to cover any excess costs– compliance or energy– that the non-GHG area should not be responsible for.

Example 2: The GHG payment is sufficient to cover compliance costs applicable to the GHG area only

Unit	Dispatch (MW)	Total Energy Cost ($)	GHG Compliance Cost ($)	Total Cost ($)	Excess Energy Payment ($)	GHG Payment ($)	Total Payment ($)
1	100	5,000	-	5,000	0	-	5,000
2	-	-	0	-	-	-	-
3	150	4,200	600	4,800	0	600	4,800
Total	250						

- LMP_N was sufficient to cover the full **energy cost** of Unit 3, but not **energy + compliance**.

- The GHG payment, funded by L_{GHG}, ensures the compliance costs are covered.

Example 2: Revenue funded by load in each area covers costs that load is responsible for

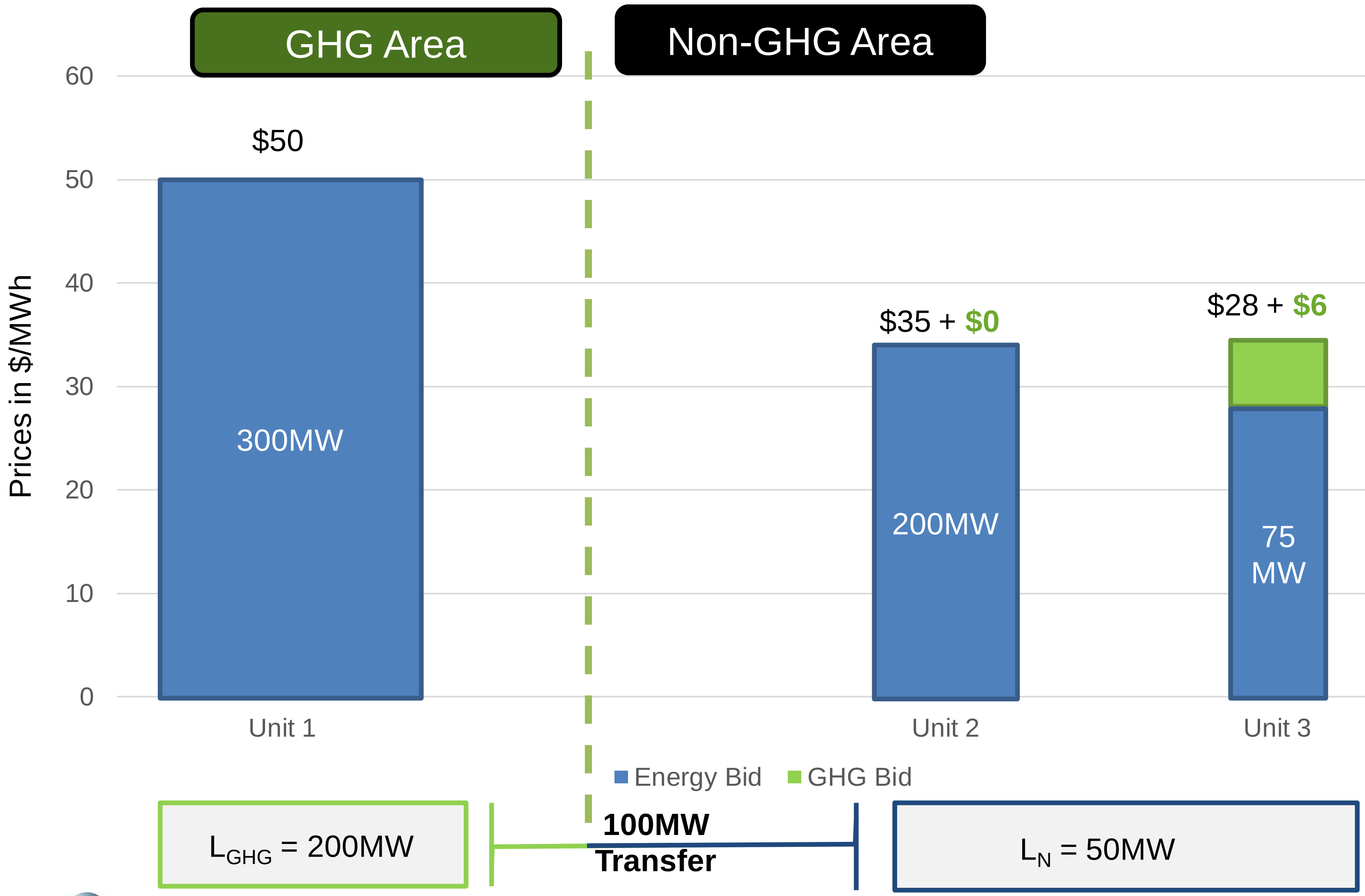
	Total Cost of Unit 1 ($)	Total Cost of Unit 2 ($)	Total Cost of Unit 3 ($)	Congestion Revenue	Load (MW)	LMP ($/MWh)	Total Payment funded by load ($)
L_{GHG}	5,000	-	3,400	1,600	200	50	10,000
L_N	-	-	1,400		50	28	1,400
Total	5,000	-	4,800	1,600			**11,400**

- $L_{GHG,}$ pays for the total cost of Units 1, the cost of 100MW of Unit 3 including it's compliance costs, and congestion.
  - Unit 3 costs $28/MWh in energy and $6/MWh in compliance.
  - Congestion is $16 * 100MW = $1,600

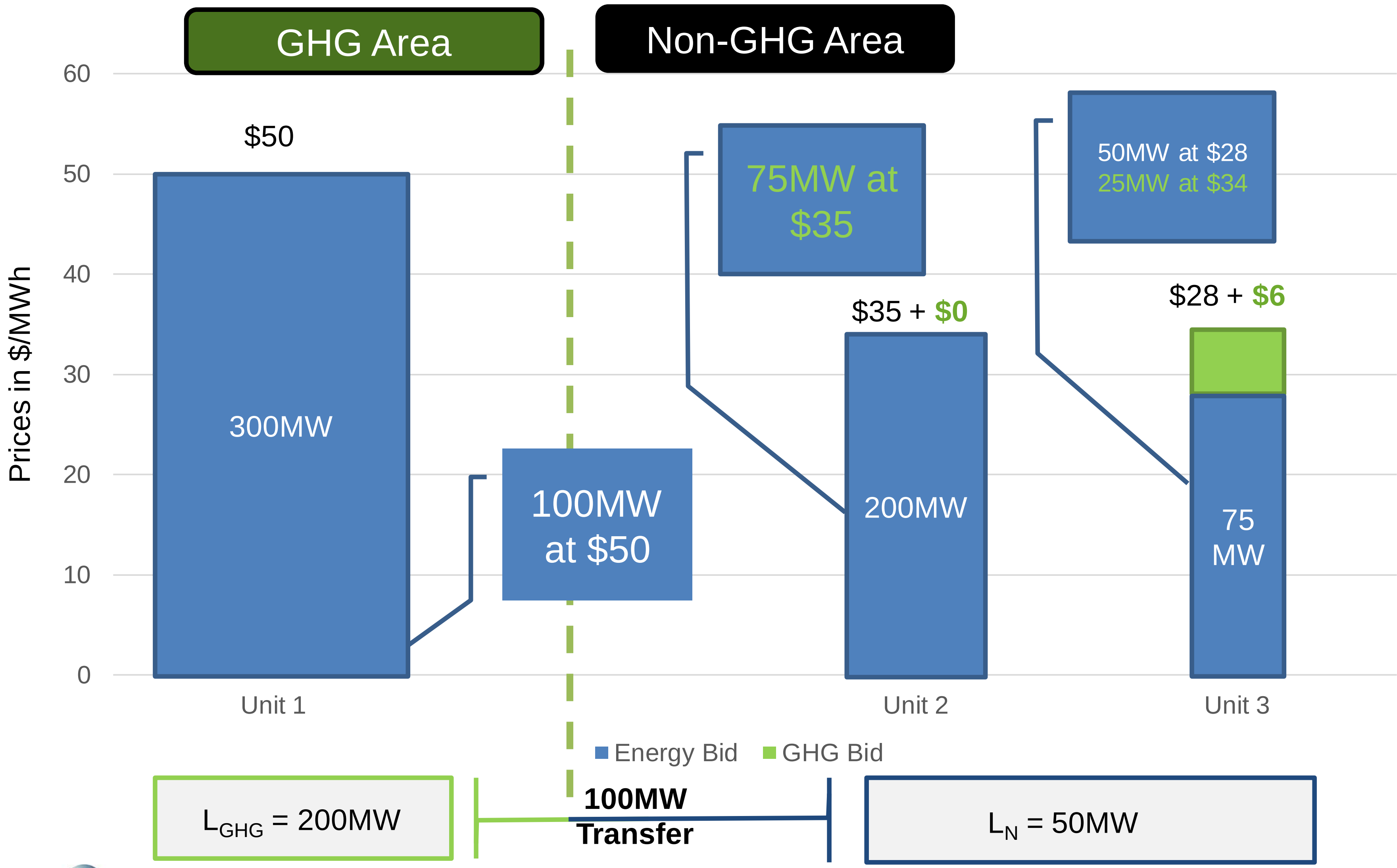
- L_N pays for the energy cost of 50MW of Unit 3 only.

EXAMPLE 3

Example 3: How should we dispatch 250MW?

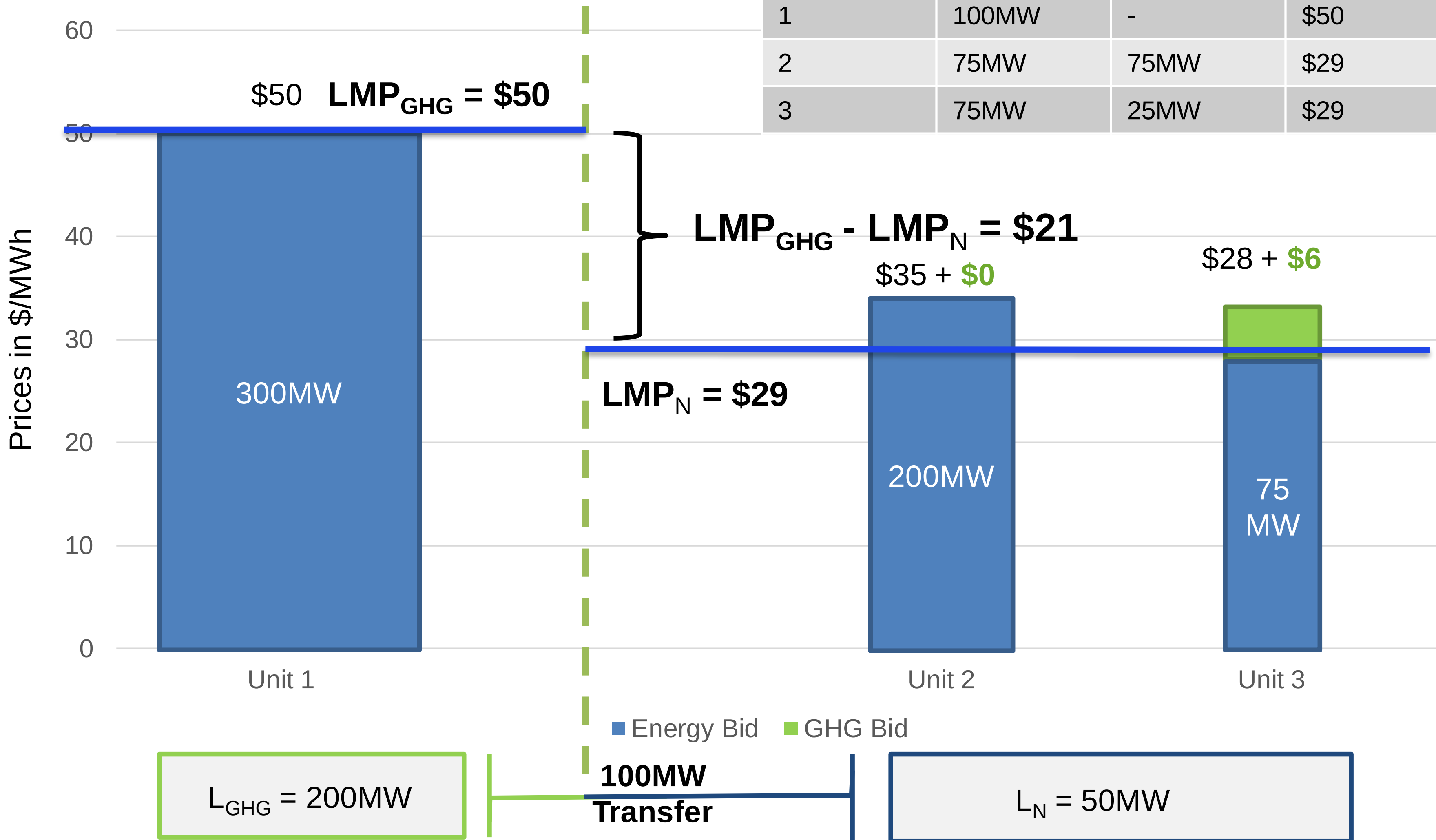


Example 3: How should we dispatch 250MW?



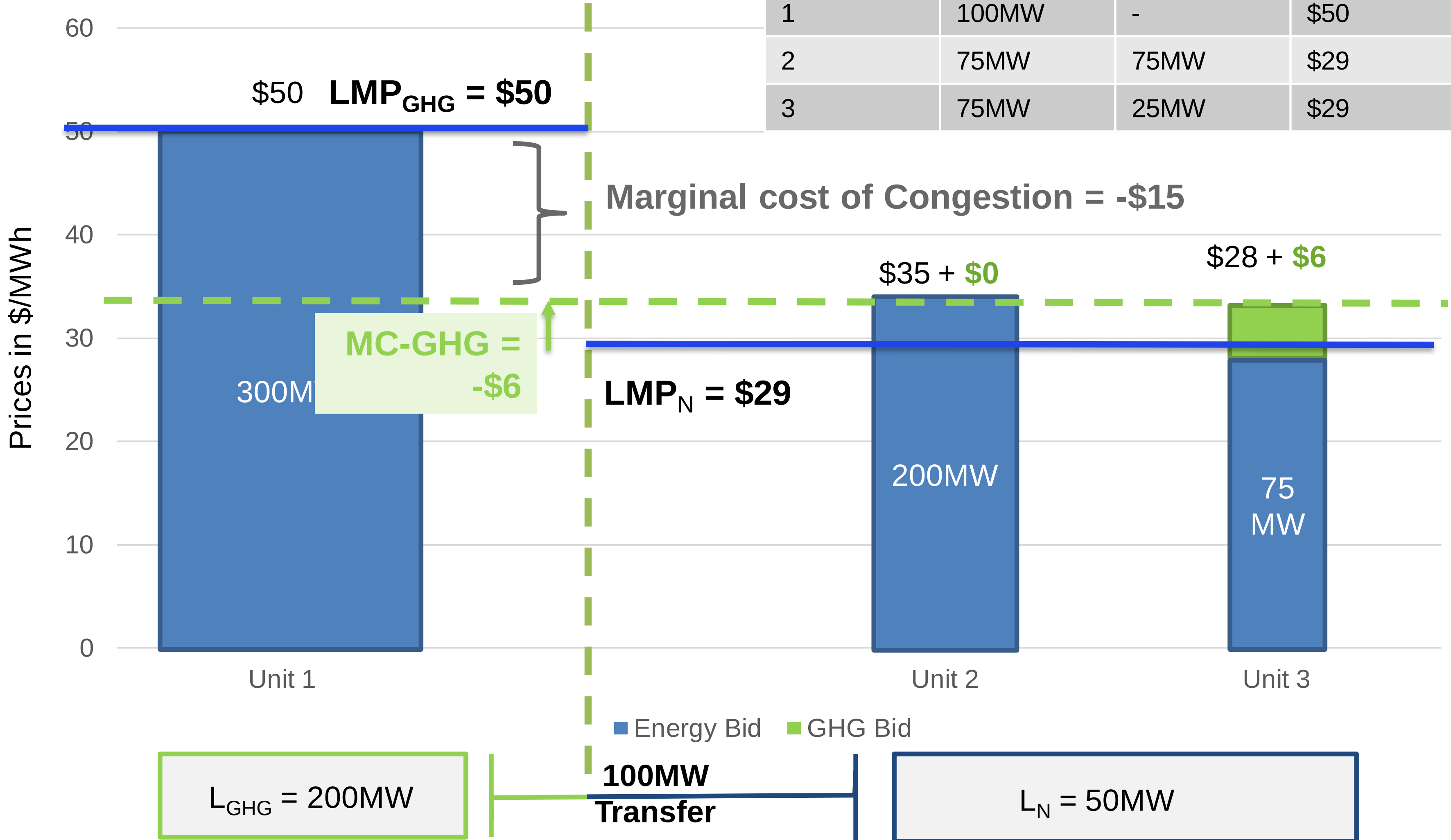
Example 3: How do we set prices?

Unit	Dispatch	Export Allocation	LMP
1	100MW	-	$50
2	75MW	75MW	$29
3	75MW	25MW	$29



Example 3: How do we set prices?

Unit	Dispatch	Export Allocation	LMP
1	100MW	-	$50
2	75MW	75MW	$29
3	75MW	25MW	$29

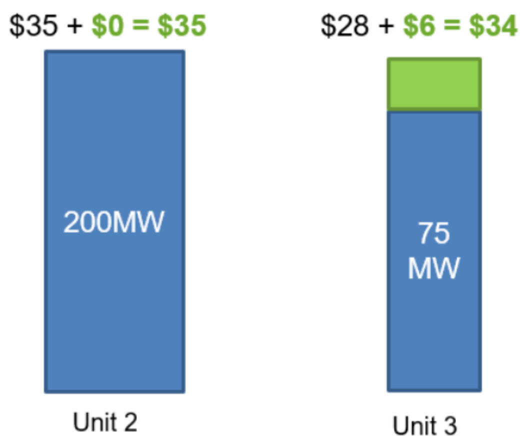


Example 3: Why is the LMP in the non-GHG area $29?

Think of it as a negotiation:

- L_{GHG} is willing to pay an additional $1/MWh for Unit 3 compared to Unit 2
- L_N is willing to pay an additional $7/MWh for Unit 3 compared to Unit 2

L_{GHG} would be indifferent between Units 2 and 3 if L_N is willing to pay an extra $1/MWh of Unit 3



	Cost of Unit 2	Cost of Unit 3
L_{GHG}	$35/MWh	$34/MWh
L_N	$35/MWh	$28/MWh

Note: The explanation in the BPMs offers a different way to think through this, described in the appendix of this presentation, but both explanations identify an opportunity cost being accounted for through the LMP_N

Example 1: Summary of LMP breakdown

- LMP GHG = $50/MWh
- LMP non-GHG = $29/MWh

- Price difference between the GHG and non-GHG areas is $21/MWh, and made up by:
  - Marginal Congestion Cost = $15/MWh
  - Marginal GHG Cost = $6/MWh

- A 100MW export allocation generates:
  - Congestion revenue = $1,500
  - GHG revenue = $600 allocated to two units
    - Unit 2 receives $450
    - Unit 3 receives $150

Example 3: The price in the GHG area, and the MC-GHG, are price signals for resources serving L_{GHG}

Unit	Dispatch (MW)	GHG Export Allocation (MW)	Energy Bid (+ Compliance) ($)	LMP_{GHG} ($/MWh)	LMP_N ($/MWh) + MC-GHG
1	100	-	50	50	-
2	75	75	35	-	35
3	75	25	34	-	35
Total	250	**100**			

Unit 1 includes compliance in it's bid and is paid LMP_{GHG} at $50/MWh.

In the non-GHG area, the price signal for resources serving the GHG area is $35: LMP_N ($29) plus the MC-GHG ($6).

The market considers the total bid cost, including compliance, for resources serving the GHG area:

- **Unit 2** is economic to serve L_{GHG} at $35/MWh
- **Unit 3** is economic to serve L_{GHG} at $34/MWh

Recall: The GHG area is indifferent between Units 2 and 3 if the non-GHG area pays an extra $1/MWh for Unit 3

Example 3: The price in the non-GHG area is the price signal for resources serving L_N

Unit	Dispatch (MW)	Energy Bid ($)	LMP_N ($/MWh)	Total Energy Cost ($)	Total Payment from LMP_N ($)	Excess Energy Payment ($)
1	100	50	-	5,000	-	-
2	75	35	29	2,625	2,175	(450)
3	75	28	29	2,100	2,175	75
Total	250			**9,200**		

Unit 2 is only economic to serve L_{GHG}. LMP_N does not send a complete price signal, and would not cover the full energy cost of this resource.

Unit 3 is economic to serve both L_N and L_{GHG}. The previous slide illustrated an extra $1/MWh from the combined LMP_N and MC-GHG. Here, we see the additional $1/MWh comes from LMP_N. This reduces the cost of this resource for the GHG area.

- **Remember:** L_N is willing to pay an additional $7/MWh for Unit 3 compared to Unit 2, but the GHG area is willing to accept just $1/MWh to be indifferent.

Example 3: All export allocations receive a GHG payment for that export allocation

Unit	Dispatch (MW)	GHG Export Allocation (MW)	MC-GHG ($/MW)	GHG Payment ($)	GHG Adder ($/MWh)	GHG Compliance Cost ($)	Payment in excess of compliance ($)
1	100	-	-	-	-	-	
2	75	75	6	450	0	0	450
3	75	25	6	150	6	150	0
Total	250	**200**					

In this example, GHG revenue covers both compliance and excess energy costs.

Unit 2 receives a GHG payment for a 75MW export allocation. This does not cover compliance but will make this resource whole.

Unit 3 receives a GHG payment for a 25MW export allocation. This covers this resource's compliance costs.

Example 3: The GHG payment makes resources whole for compliance and energy

Unit	Dispatch (MW)	Total Energy Cost ($)	GHG Compliance Cost ($)	Total Cost ($)	Excess Energy Payment ($)	GHG Payment ($)	Total Payment ($)
1	100	5,000	-	5,000	0	-	5,000
2	75	2,625	0	2,625	(450)	450	2,625
3	75	2,100	150	2,250	75	150	2,325
Total	250						

- **Unit 2** is paid $2,625, which equals it's total cost.
  - LMP_N at $29/MWh only covers $2,175 of the total energy cost, so the resource is made whole through $450 GHG payment
- **Unit 3** is paid $2,175 and would only need $75 to be made whole for compliance, but the GHG area only is responsible for compliance. Unit 3 receives it's full compliance cost, $150, from the GHG payment.

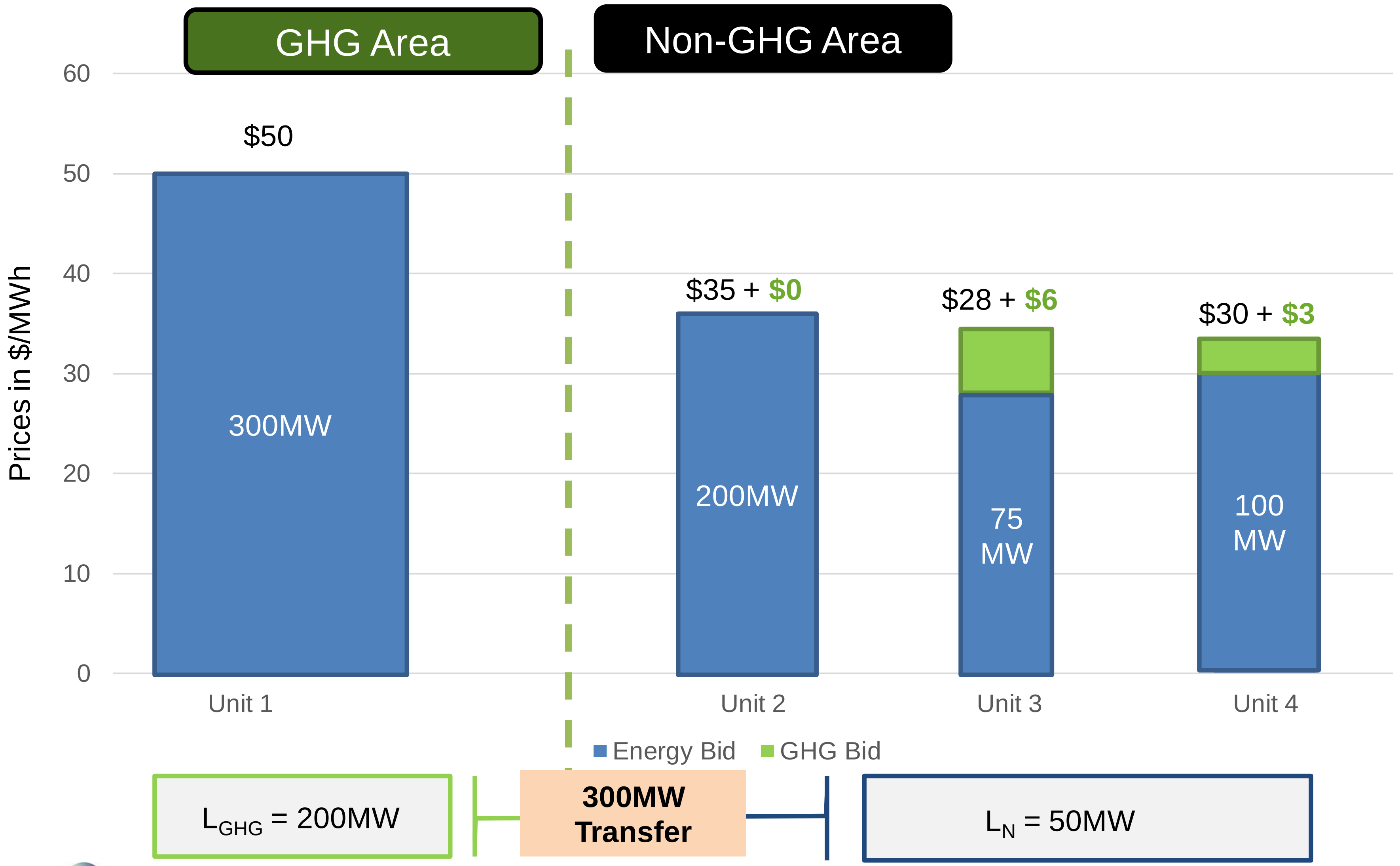
Example 3: Revenue funded by load in each area covers costs that load is responsible for

	Total Cost of Unit 1 ($)	Total Cost of Unit 2 ($)	Total Cost of Unit 3 ($)	Congestion Revenue	Load (MW)	LMP ($/MWh)	Total Payment funded by load ($)
L_{GHG}	5,000	2,625	875	1,500	200	50	10,000
L_N	-	-	1,450	-	50	29	1,450
Total	5,000	2,625	2,325	1,500			**11,450**

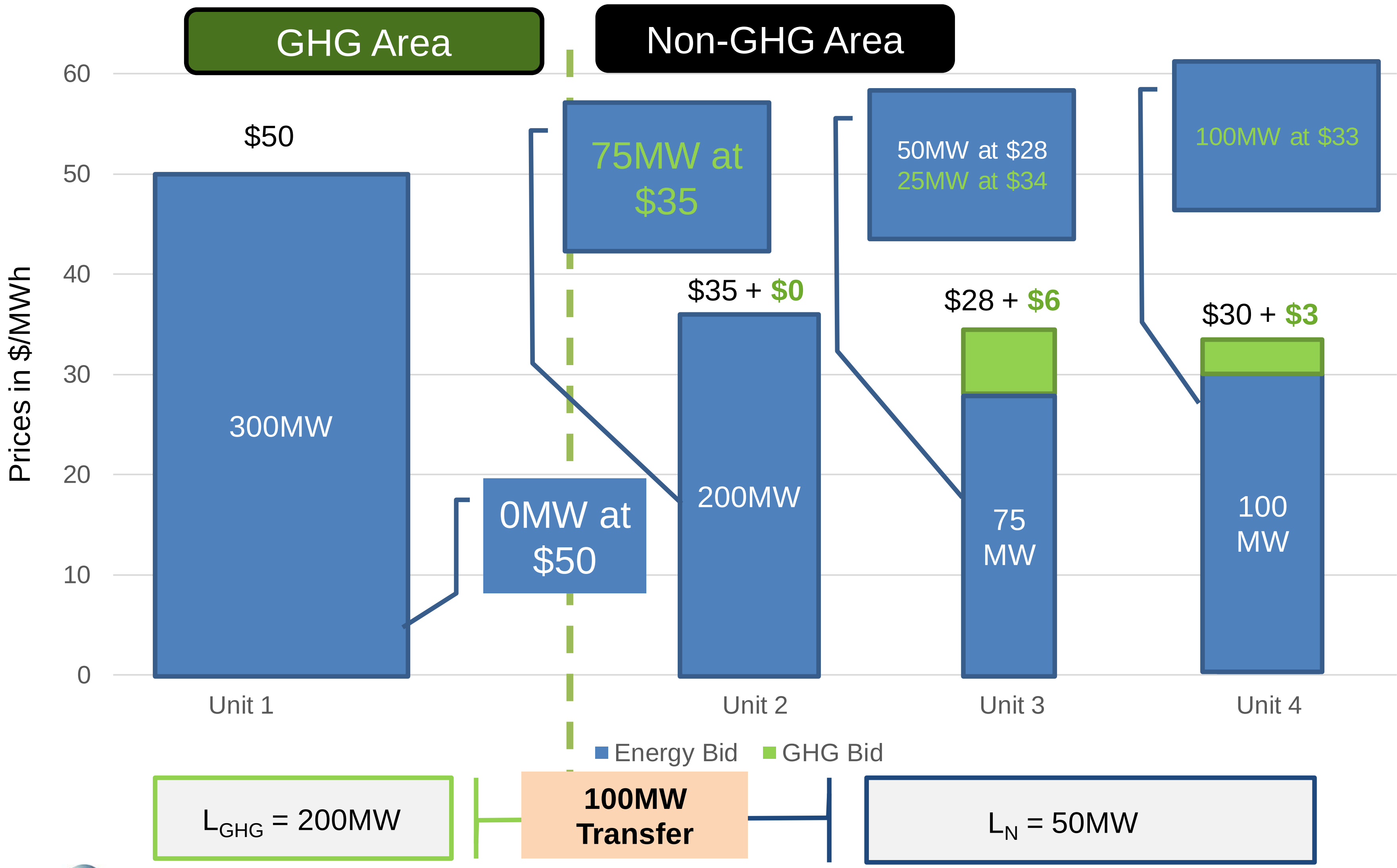
- $L_{GHG,}$ pays for the total cost of Units 1, 75MW of Unit 2, 25MW of Unit 3, and congestion.
  - Units 2 and 3 cost ($29/MWh + $6/MWh) for 75 and 25MWs respectively
  - Congestion is $15 * 100MW = $1,500
- L_N pays for the cost of 50MW Unit 3 at $29/MWh

EXAMPLE 4

Example 4: How should we dispatch 250MW?

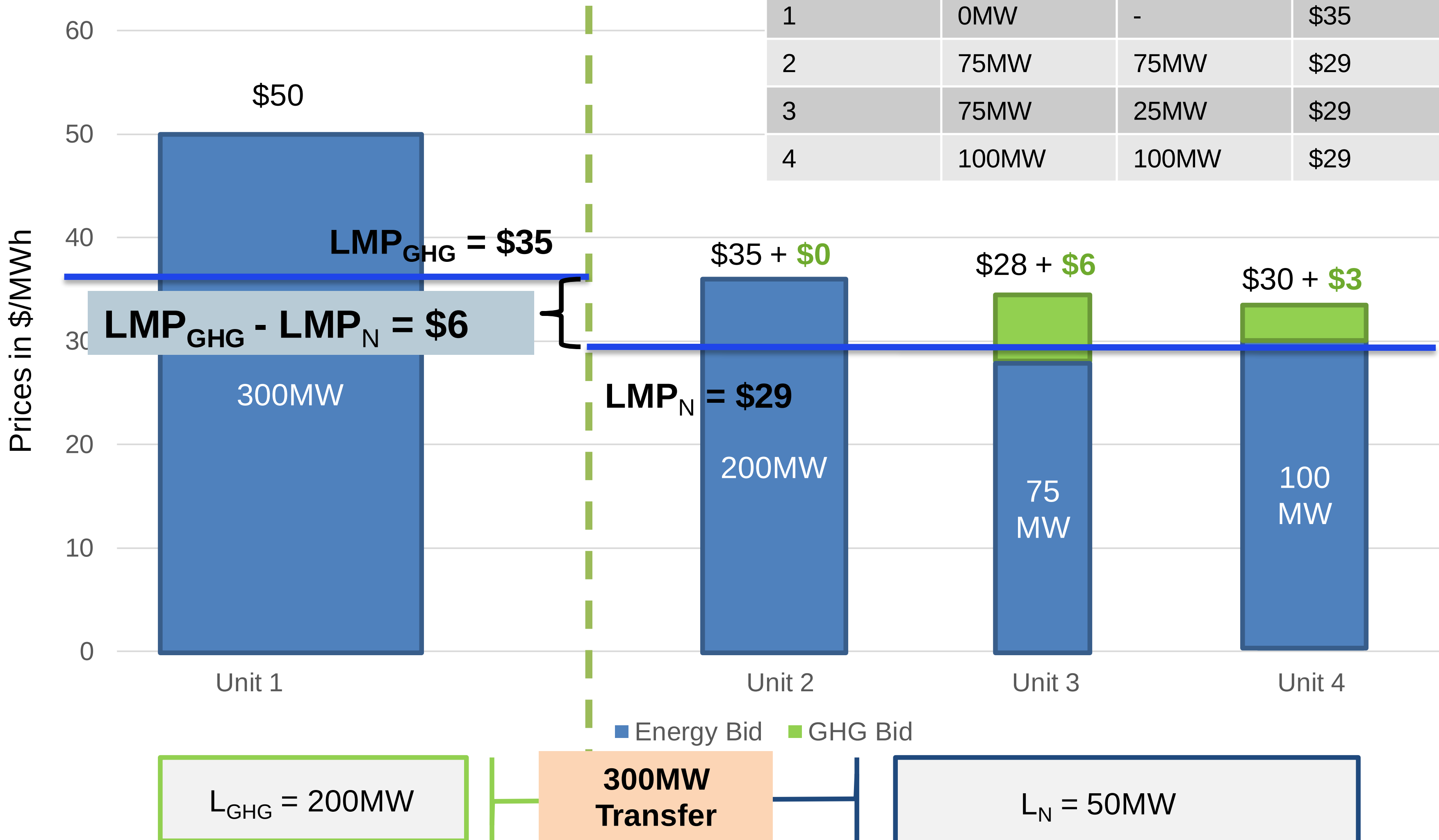


Example 4: How should we dispatch 250MW?



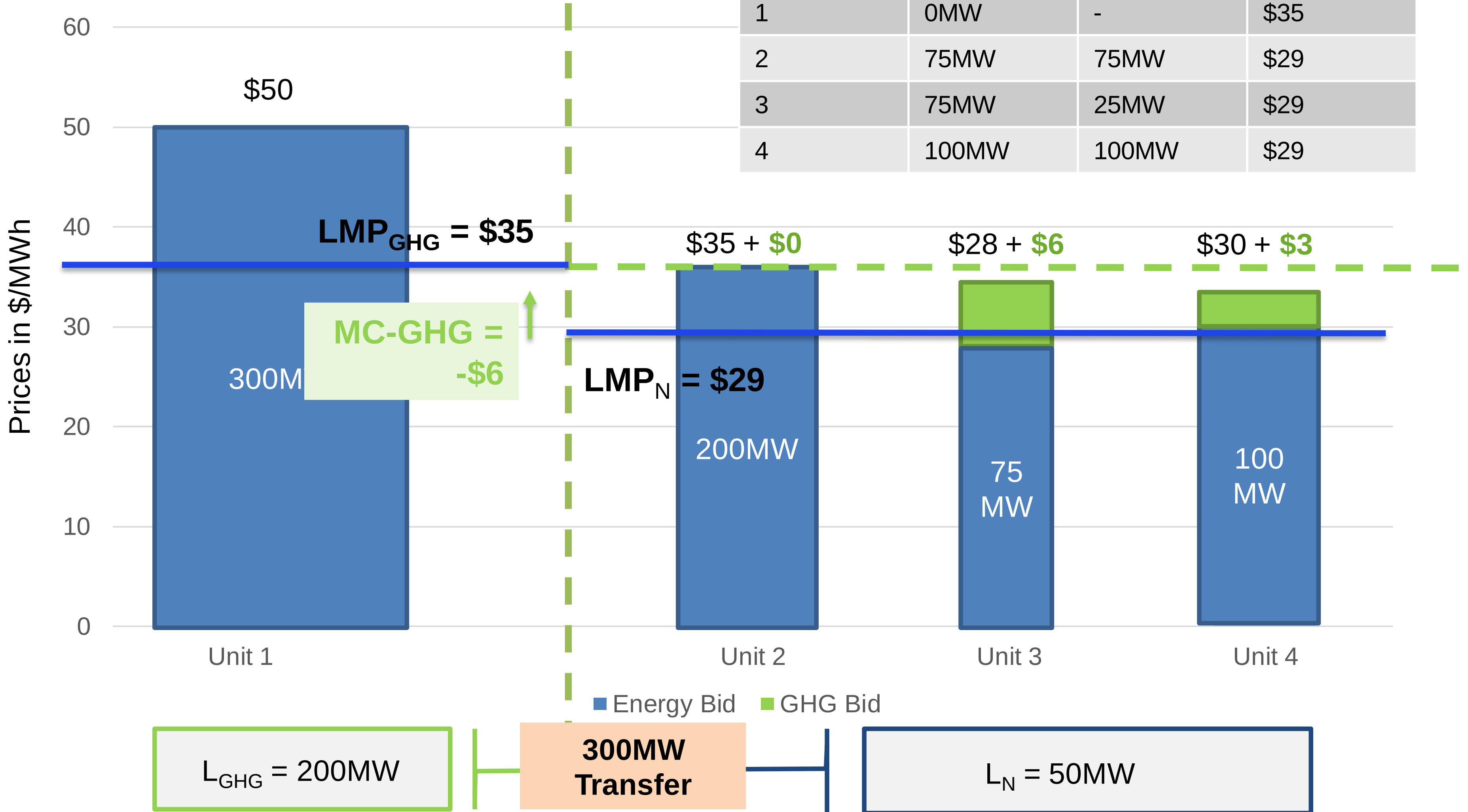
Example 4: How do we set prices?

Unit	Dispatch	Export Allocation	LMP
1	0MW	-	$35
2	75MW	75MW	$29
3	75MW	25MW	$29
4	100MW	100MW	$29



Example 4: How do we set prices?

Unit	Dispatch	Export Allocation	LMP
1	0MW	-	$35
2	75MW	75MW	$29
3	75MW	25MW	$29
4	100MW	100MW	$29



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Example 4: Summary of LMP breakdown

- LMP GHG = $35/MWh
- LMP non-GHG = $29/MWh

- Price difference between the GHG and non-GHG areas is $6/MWh, and **made up entirely by GHG**:
  - Marginal Congestion Cost = $0/MWh
  - Marginal GHG Cost = $6/MWh

- A 200MW export allocation generates:
  - Congestion revenue = $0
  - GHG revenue = $1,200 allocated to three units

Example 4: The price in the GHG area, and the MC-GHG, are price signals for resources serving L_{GHG}

Unit	Dispatch (MW)	GHG Export Allocation (MW)	Energy Bid (+ Compliance) ($)	LMP_{GHG} ($/MWh)	LMP_N ($/MWh) + MC-GHG
1	0	-	50	35	-
2	75	75	35	-	35
3	75	25	34	-	35
4	100	100	33		35
Total	250	**200**			

Unit 1 includes compliance in it's bid. At **LMP_{GHG} = $35/MWh, unit 1 is not economic.**

In the non-GHG area, the price signal for resources serving the GHG area is $35: LMP_N ($28) plus the MC-GHG ($6).

The market considers the total bid cost, including compliance, for resources serving the GHG area: **Units 2, 3, and 4** are economic to serve the GHG area.

Example 4: The price in the non-GHG area is the price signal for resources serving L_N

Unit	Dispatch (MW)	Energy Bid ($)	LMP_N ($/MWh)	Total Energy Cost ($)	Total Payment from LMP_N ($)	Excess Energy Payment ($)
1	0	50	-	-	-	-
2	75	35	29	2,625	2,175	(450)
3	75	28	29	2,100	2,175	75
4	100	30	29	3,000	2,900	(100)
Total	250			**7,725**	**7,250**	

Units 2, 3, and 4 are dispatched in the non-GHG area but the only unit economic to serve the non-GHG area is **Unit 3** which costs $28/MWh and is paid LMP_N ($28).

Units 2 and 4 are not economic to serve the non-GHG area. LMP_N is not a sufficient price signal, and would not cover the total energy cost of these resources.

Example 4: All export allocations receive a GHG payment for that export allocation

Unit	Dispatch (MW)	GHG Export Allocation (MW)	MC-GHG ($/MW)	GHG Payment ($)	GHG Adder ($/MWh)	GHG Compliance Cost ($)	Payment in excess of compliance ($)
1	-	-	-	-	-	-	
2	75	75	6	450	0	0	450
3	75	25	6	150	6	150	0
4	100	100	6	600	3	300	300
Total	250	**200**					

In this example, all 200MW of L_{GHG} are served by attributed resources.

Units 3 and 4 have compliance costs which are fully covered by the GHG payment.

Units 2 and 4 receive payment in excess of compliance which will cover energy costs in excess of LMP_N.

Example 4: The GHG payment is sufficient to cover compliance costs applicable to the GHG area only

Unit	Dispatch (MW)	Total Energy Cost ($)	GHG Compliance Cost ($)	Total Cost ($)	Excess Energy Payment ($)	GHG Payment ($)	Total Payment ($)
1	-	-	-	-	-	-	-
2	75	2,625	0	2,625	(450)	450	2,625
3	75	2,100	150	2,250	75	150	2,325
4	100	3,000	300	3,300	(100)	600	3,500
Total	250						

- **Unit 2** is the marginal unit in the non-GHG area serving the GHG area.
- **Unit 3** receives a surplus energy payment from the non-GHG area, and compliance is fully covered by the GHG area.
- **Unit 4** is only economic to serve the GHG area and is relatively cheaper than Unit 2, so receives a GHG payment to cover **both compliance and surplus revenue.**

Example 4: Revenue funded by load in each area covers costs that load is responsible for

	Total Cost of Unit 1 ($)	Total Cost of Unit 2 ($)	Total Cost of Unit 3 ($)	Total Cost of Unit 4 ($)	Congestion Revenue	Load (MW)	LMP ($/MWh)	Total Payment funded by load ($)
L_{GHG}	-	2,625	875	3,500	-	200	35	7,000
L_N	-	0	1,450	0	-	50	29	1,450
Total	0	2,625	2,325	3,500	0			**8,450**

- $L_{GHG,}$ pays for 75MW of Unit 2, 25MW of Unit 3, and 100MW of Unit 4 at $35/MWh.
- L_N pays for the cost of Unit 3 only.

Takeaways

- When determining if prices are efficient for the non-GHG area, we compare the energy bid component only to the LMP_N
- When determining if prices are efficient for the GHG area, we compare the combined energy and GHG cost of allocated resources to the LMP_N + MC-GHG
- The LMP in the GHG area, and energy bids in the GHG area, already reflect a compliance cost

Energy Bid ($)	LMP_N ($/MWh)
50	-
35	29
28	29
30	29

Energy Bid (+ Compliance) ($)	LMP_{GHG} ($/MWh)	LMP_N ($/MWh) + MC-GHG
50	35	-
35	-	35
34	-	35
33		35

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Takeaways

- The MC-GHG signals revenue, funded by the GHG area, that gets allocated to resources in the non-GHG area to cover all compliance costs, and energy in excess of the price in the non-GHG area.

- Load in each area pays for what load is responsible for.

Wrapping Up

- Reminder: The full PDF of this presentation can be found on the ISO stakeholder initiative page Greenhouse gas coordination working groups

- Please send any questions, comments, or feedback on this training to ISOStakeholderAffairs@caiso.com with "GHG Price Formation" in the subject line
  - The ISO will collect the questions and post responses in the form of an FAQ to the initiative webpage

Chapter 5

APPENDIX

Training Center Links

- Training Center landing page: Training center | California ISO (caiso.com)

- Market Pricing: https://www.caiso.com/content/cbt/market-pricing/story.html
  - How bid prices determine the price of energy
  - LMPs and LMP components

- Settlements: Settlements and metering | California ISO (caiso.com)
  - How LMPs translate to payments to resources

Changing the sign on LMP components

- Resources are settled at their LMP which is made up of energy and component parts.
- Moving from a single SMEC to BA-specific MECs
  - Removes the CAISO as the reference bus
  - Facilitates settlement for transfers
- The marginal cost of GHG (MC-GHG) component of the LMP goes from a negative to a positive component for attribution

Resources in the non-GHG area that are not attributed to the GHG area respond to the price without GHG

In this example, assume no congestion or losses. The price separation between the GHG and non-GHG areas is entirely made up of GHG. There is one GHG area, so MC-GHG is a single value that applies to the whole market.

	Today in the GHG area	Tomorrow in the GHG area
LMP_{GHG}	**SMEC** = 20	$\mathbf{MEC_{GHG}}$ = 20

LMP for resources in the non-GHG area is $15/MWh:

	Today in the non-GHG area	Tomorrow in the non-GHG area
LMP_{BA1}	**SMEC – MC-GHG** = 20 – 5 = 15	$\mathbf{MEC_{BA1}}$ = 15
LMP_{BA2}	**SMEC – MC-GHG** = 20 – 5 = 15	$\mathbf{MEC_{BA2}}$ = 15

Resources dispatched to serve the non-GHG area are paid the LMP in their area ($15). The total cost is funded by load in that area ($15/MWh).

Resources in the non-GHG area that are attributed to the GHG area respond to a price signal that includes GHG

In this example, assume no congestion or losses. The price separation between the GHG and non-GHG areas is entirely made up of GHG. There is one GHG area, so MC-GHG is a single value that applies to the whole market.

	Today in the GHG area	Tomorrow in the GHG area
LMP_{GHG}	**SMEC** = 20	$\mathbf{MEC_{GHG}}$ = 20

LMP for attributed resources in the non-GHG area is $20/MWh:

	Today in the non-GHG area	Tomorrow in the non-GHG area
BA1 LMP_{GHG}	**SMEC** = 20	$\mathbf{MEC_{BA1}}$ **+ MC-GHG** = 15 + 5 = 20
BA2 LMP_{GHG}	**SMEC** = 20	$\mathbf{MEC_{BA2}}$ **+ MC-GHG** = 15 + 5 = 20

Attributed resources are paid the non-GHG area LMP ($15) + MC-GHG ($5/MWh). The total cost is funded by GHG area load which pays the GHG area LMP ($20/MWh).

Resources in the non-GHG area that are not attributed to the GHG area respond to the price without GHG

Assume no internal congestion and no losses– each BA has a single LMP. Price separation between the GHG BA and BA1 is due to both GHG and congestion.

	Today in the GHG area	Tomorrow in the GHG area
LMP_{GHG}	**SMEC** = 20	**MEC_{GHG}** = 20

LMPs for resources in the non-GHG area:

	Today in the non-GHG area	Tomorrow in the non-GHG area
LMP_{BA1}	**SMEC – MC-GHG – $Congestion_{BA1}$** = 20 – 5 – 2 = 13	**MEC_{BA1}** = 13
LMP_{BA2}	**SMEC – MC-GHG – $Congestion_{BA2}$** = 20 – 5 – 0 = 15	**MEC_{BA2}** = 15

While GHG creates price separation between the GHG and non-GHG areas, congestion can create price separation between BAs.

Resources in the non-GHG area that are attributed to the GHG area respond to a price signal that includes GHG

Assume no internal congestion and no losses– each BA has a single LMP. Price separation between the GHG BA and BA1 is due to both GHG and congestion.

	Today in the GHG area	Tomorrow in the GHG area
LMP_{GHG}	**SMEC** = 20	$\mathbf{MEC_{GHG}}$ = 20

GHG BA load funds $2/MWh congestion for transfers from BA1

LMPs for attributed resources in the non-GHG area:

	Today in the non-GHG area	Tomorrow in the non-GHG area
BA1 LMP_{GHG}	**SMEC – $\mathbf{Congestion_{BA1}}$** = 20 – 2 = 18	$\mathbf{MEC_{BA1}}$ **+ MC-GHG** = 13 + 5 = 18
BA2 LMP_{GHG}	**SMEC – $\mathbf{Congestion_{BA2}}$** = 20 –0 = 20	$\mathbf{MEC_{BA2}}$ **+ MC-GHG** = 15 + 5 = 20

Even though the MC-GHG is consistent across all non-GHG area BAs, resources in each BA receive different clearing prices for transfers due to congestion. Transfers between BA1 and the GHG area BA generate congestion revenue ($2/MWh) in addition to the MEC + MC-GHG ($18/MWh).

Example 3: Why is the LMP in the non-GHG area $29?

Compare the incremental cost of serving L_N , given re-dispatch of L_{GHG} , under two scenarios:

Change to system costs from swapping 1MW of L_N with L_{GHG}	Change to system costs to meet L_{GHG}	Incremental cost to the system of meeting the next MW of L_N
Scenario 1: If we swap a MW of Unit 3 to serve L_N instead of L_{GHG} , the system cost goes down by $6 because each MW of Unit 3 is $6 cheaper for L_N compared to L_{GHG}. $34 - $28 = $6	To meet L_{GHG} , 1 MW of Unit 2 costs $35.	$35 + (-$6) = $29 **Meeting the next MW of L_N with Unit 3 would cost $29, and minimize total system costs.**
Scenario 2: If we swap a MW of Unit 2 to serve L_N instead of L_{GHG} , there's no change in system cost as Unit 2 costs $35 for both L_N and L_{GHG}. $35 - $35 = $0 change in cost	To meet L_{GHG} , 1 MW of Unit 3 costs $34.	$34 + 0 = $34 Meeting the next MW of L_N with Unit 2 would not minimize total system costs.