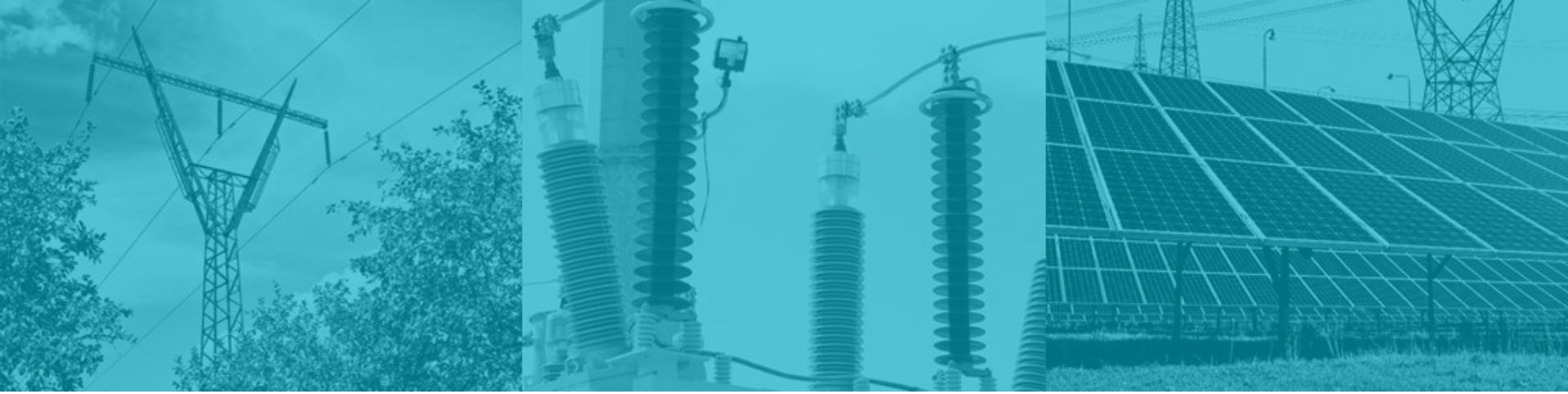


ERCOT Market Education

Resources and Real-Time Operations

2025_03 Resource_RT_Ops

Greetings and Introductions

Suite of Resource Courses

Format	Title
WBT	Resources in ERCOT
	Resource Responsibilities in ERCOT

Format	Title	Topic
ILT	Resources and Day-Ahead Operations	Resource Constraints in the Day-Ahead Market
		Resource Commitment in the Day-Ahead Market
		Resource Commitment after the Day-Ahead Market
	Resources and Real-Time Operations	Resource Dispatch in Real-Time
		Resource Reserve Deployment in Real-Time
		Resources and their Financial Impacts

WebEx Tips

- Windows
- Buttons

Attendance

Questions / Chat

PROTOCOL DISCLAIMER

This presentation provides a general overview of the Texas Nodal Market and is not intended to be a substitute for the ERCOT Protocols, as amended from time to time. If any conflict exists between this presentation and the ERCOT Protocols, the ERCOT Protocols shall control in all respects.

For more information, please visit:

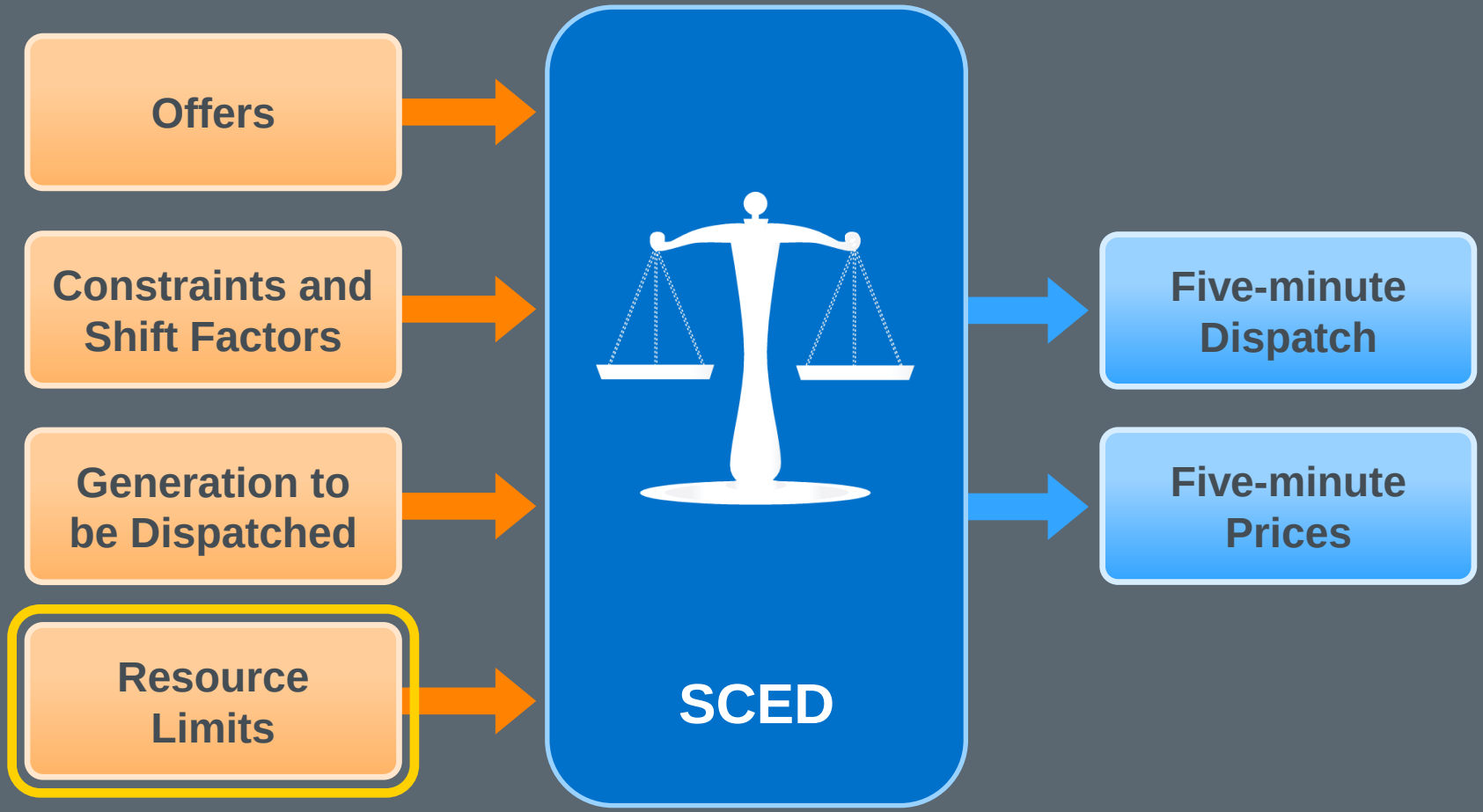
http://www.ercot.com/mktrules/nprotocols/

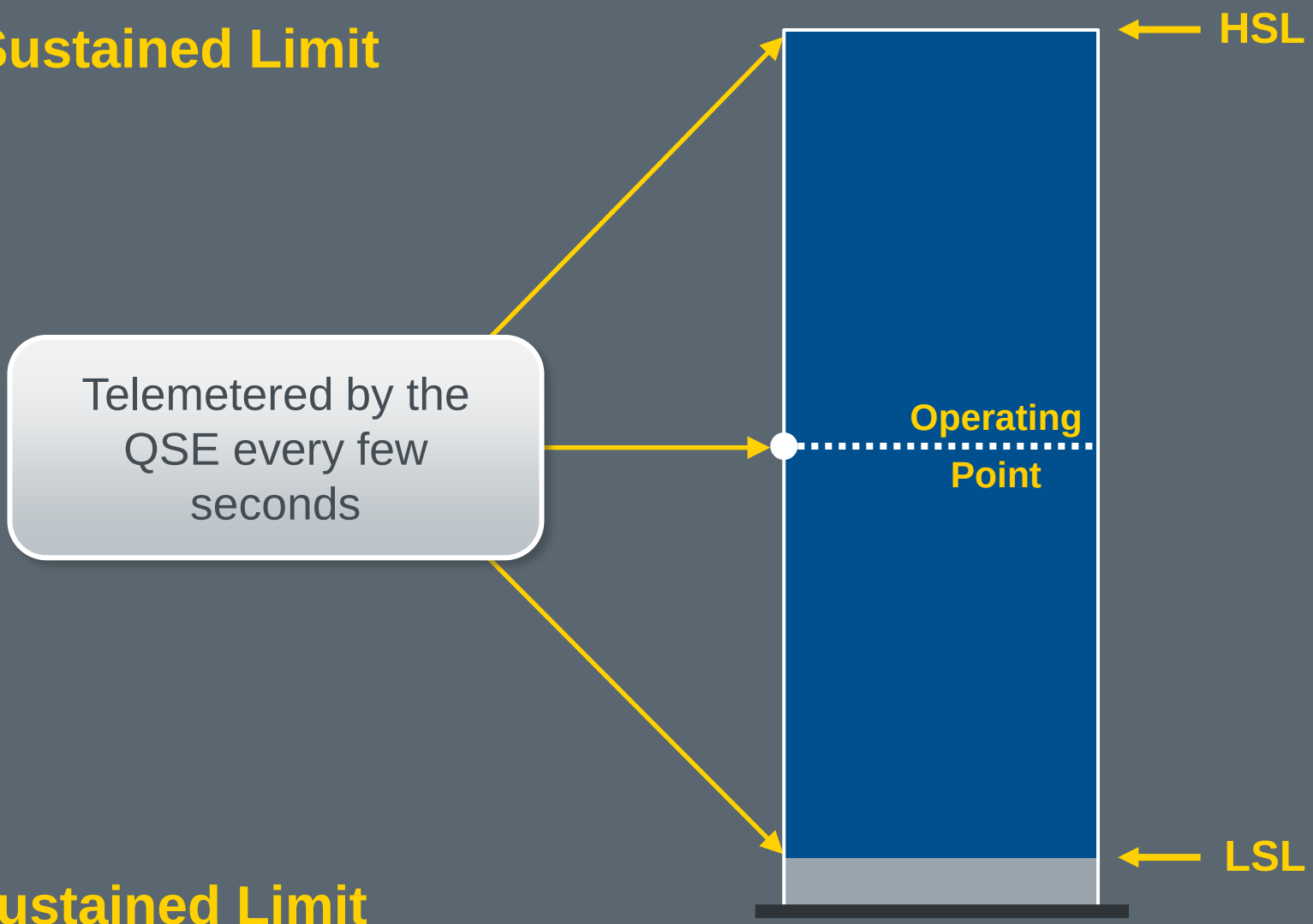
Resource Dispatch in Real-Time

1 Resource Limits in Real-Time Dispatch

2 Real-Time Dispatch Process

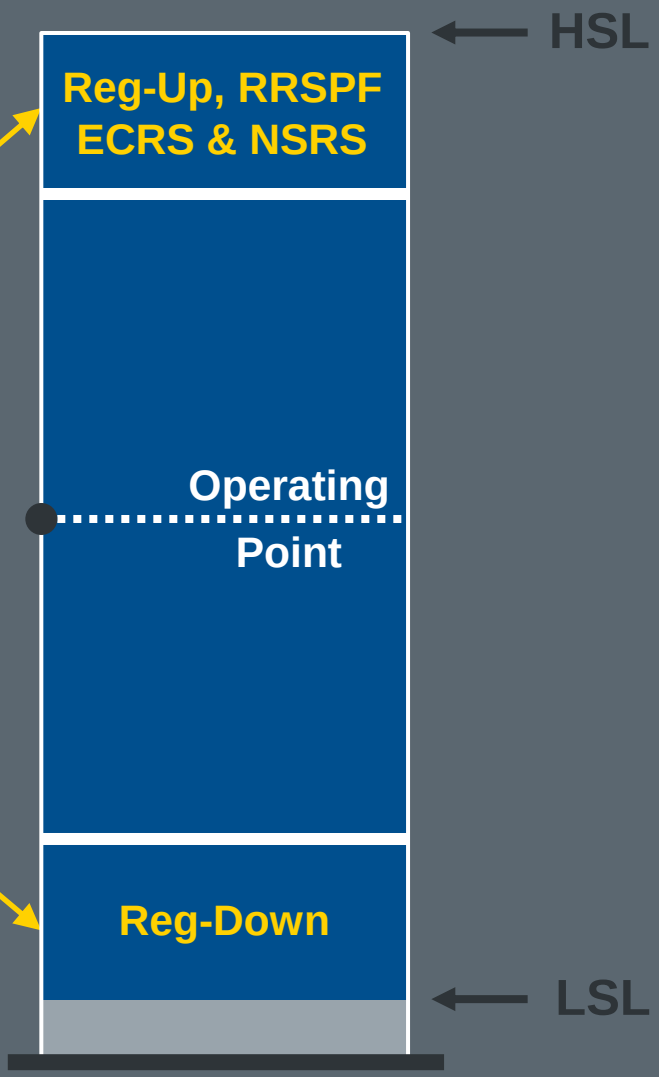
Security Constrained Economic Dispatch




High Sustained Limit
HSL
Telemetered by the QSE every few seconds
Operating Point
LSL
Low Sustained Limit

High Sustained Limit

Telemetered by the QSE every few seconds



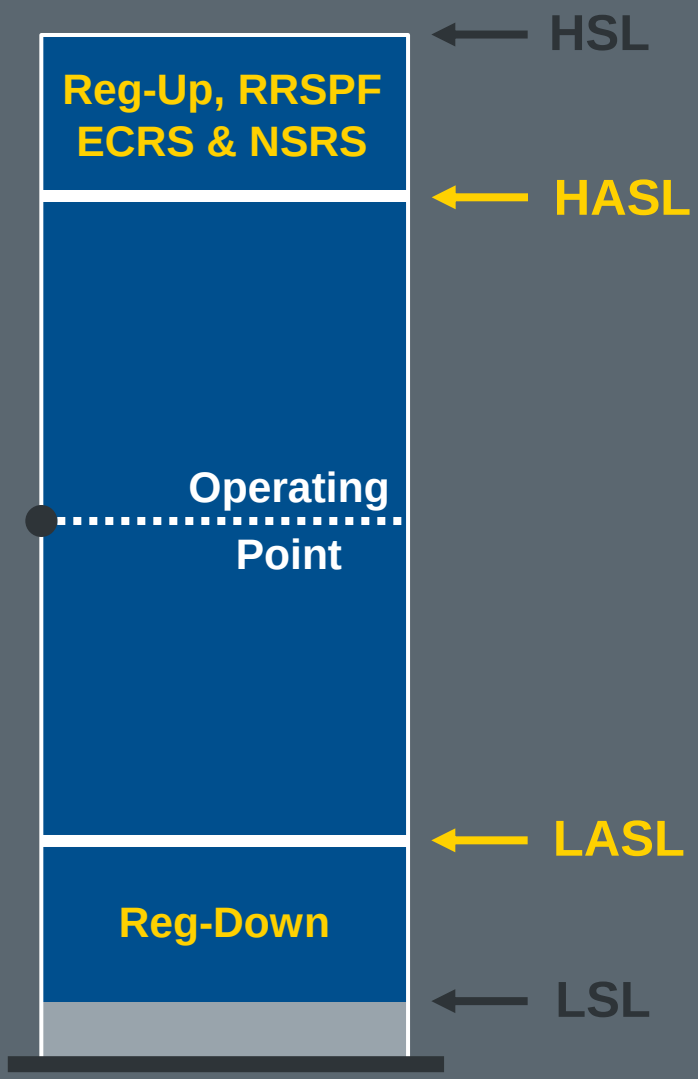
Low Sustained Limit

High Ancillary Service Limit

= HSL – Reg-Up Responsibility
– RRSPF Schedule
– ECRS Schedule
– Non-Spin Schedule

Low Ancillary Service Limit

= LSL + Reg-Down Responsibility



SCED Up Ramp Rate (SURAMP)

= Up Ramp Rate

– (1- RDSDEPLP) * (Reg-Up Resp / 7)

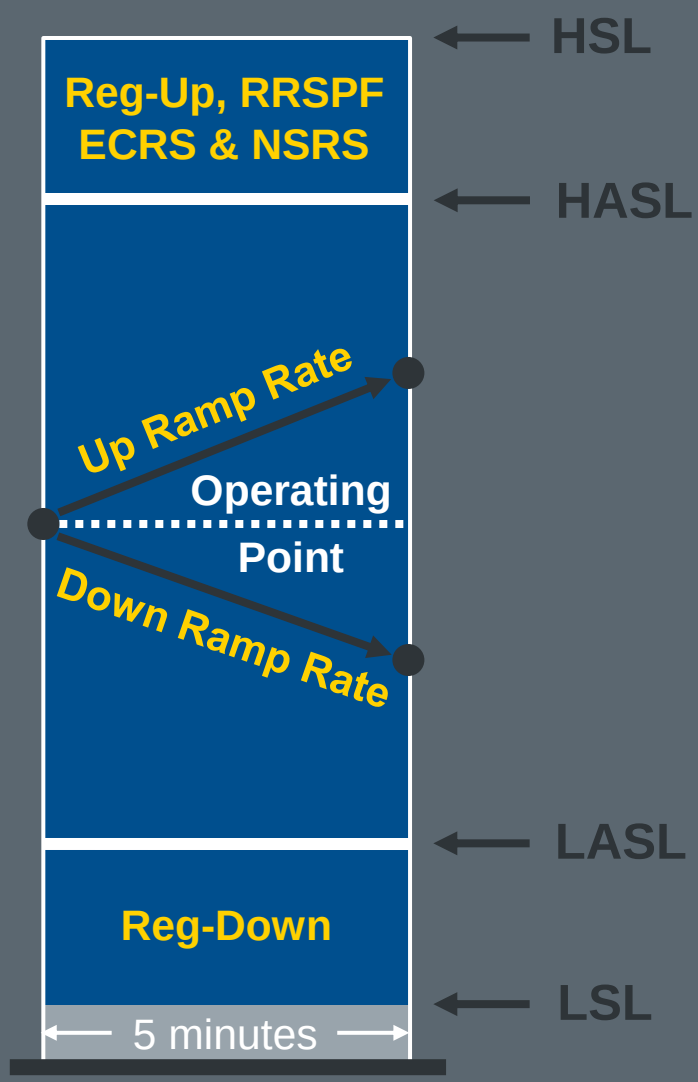
Reg-down Deployment Percentage

SCED Down Ramp Rate (SDRAMP)

= Down Ramp Rate

– (1- RUSDEPLP) * (Reg-Down Resp / 7)

Reg-up Deployment Percentage

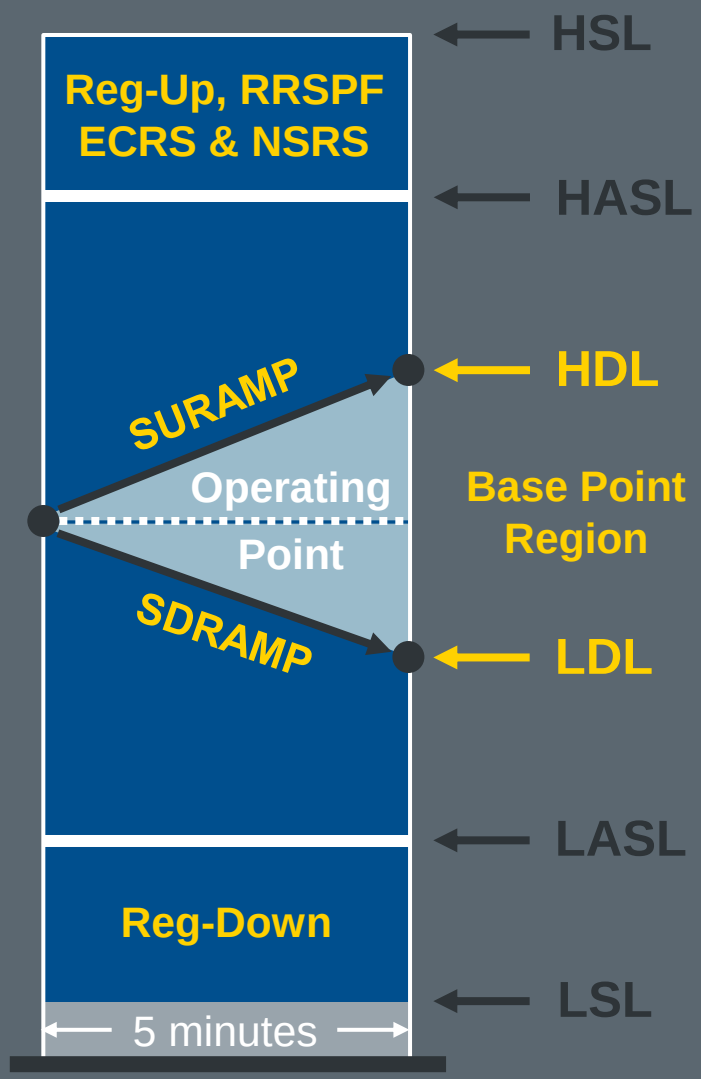


High Dispatch Limit

HDL = Operating Point + (SURAMP * 5)

Low Dispatch Limit

LDL = Operating Point – (SDRAMP * 5)

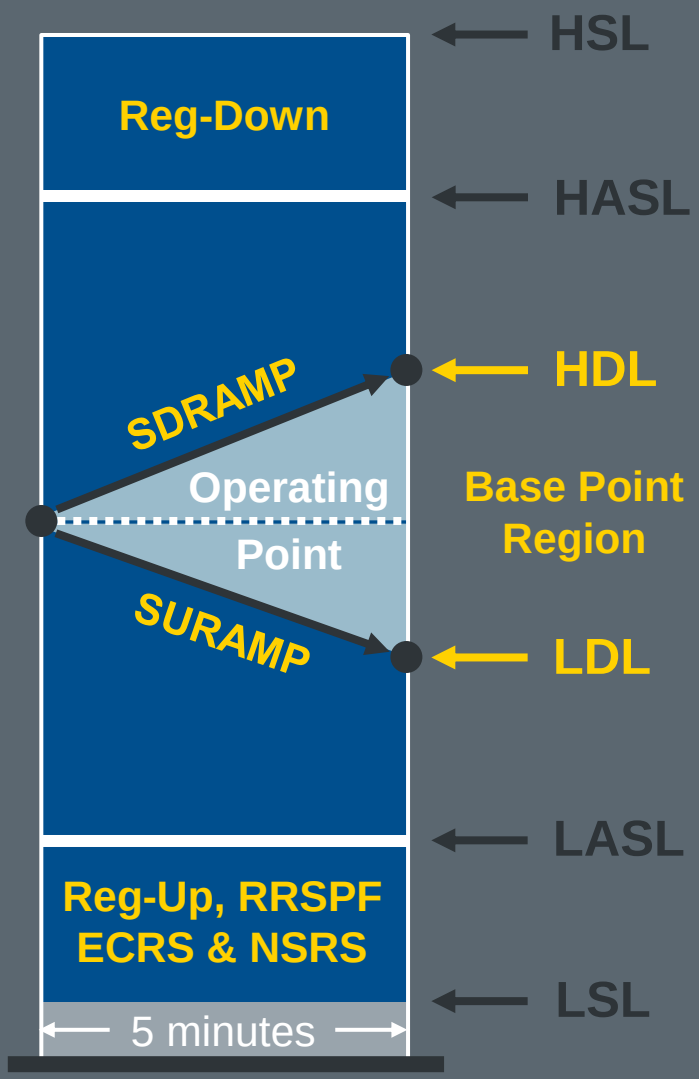


High Dispatch Limit

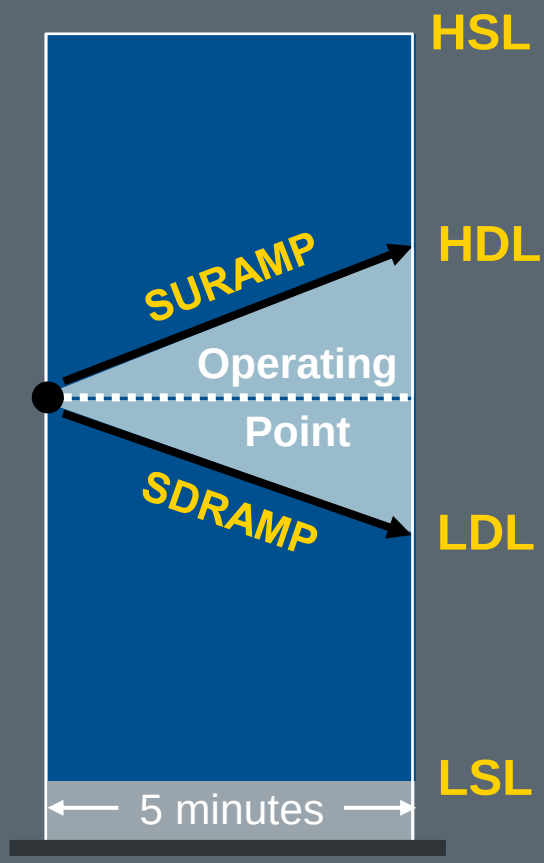
HDL = Operating Point + (SDRAMP * 5)

Low Dispatch Limit

LDL = Operating Point – (SURAMP * 5)



Generator has a current operating point of 150MW

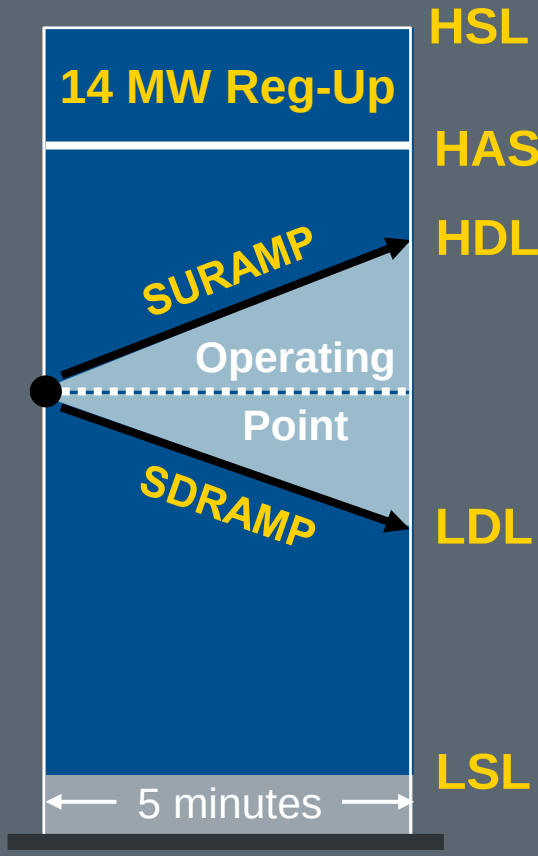


Ramp Rates:

- Normal Up = 3MW/min
- Normal Down = 4MW/min

What are HDL and LDL?

Generator has a current operating point of 150MW



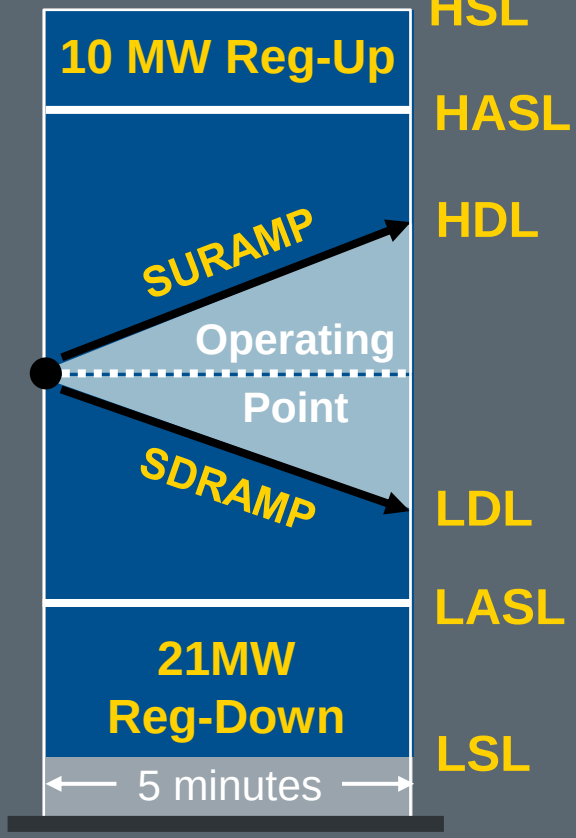
Ramp Rates:

- Normal Up = 3MW/min
- Normal Down = 4MW/min

Reg-Down deployment percentage = 50%

What is HDL?

Generator has a current operating point of 150MW



Ramp Rates:

- Normal Up = 3MW/min
- Normal Down = 4MW/min

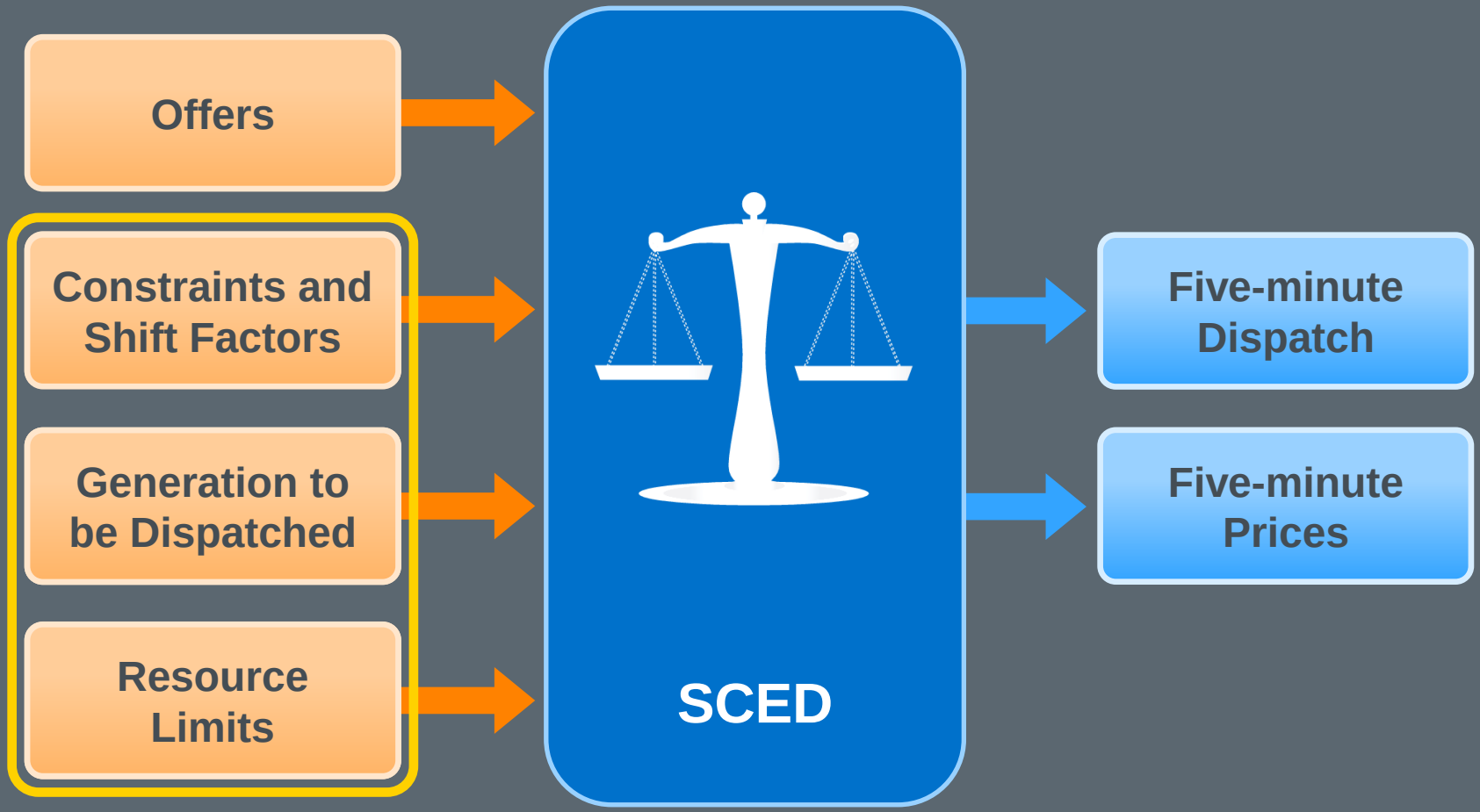
Reg-Up deployment percentage = 0%

What is LDL?

1 Resource Limits in Real-Time Dispatch

2 Real-Time Dispatch Process

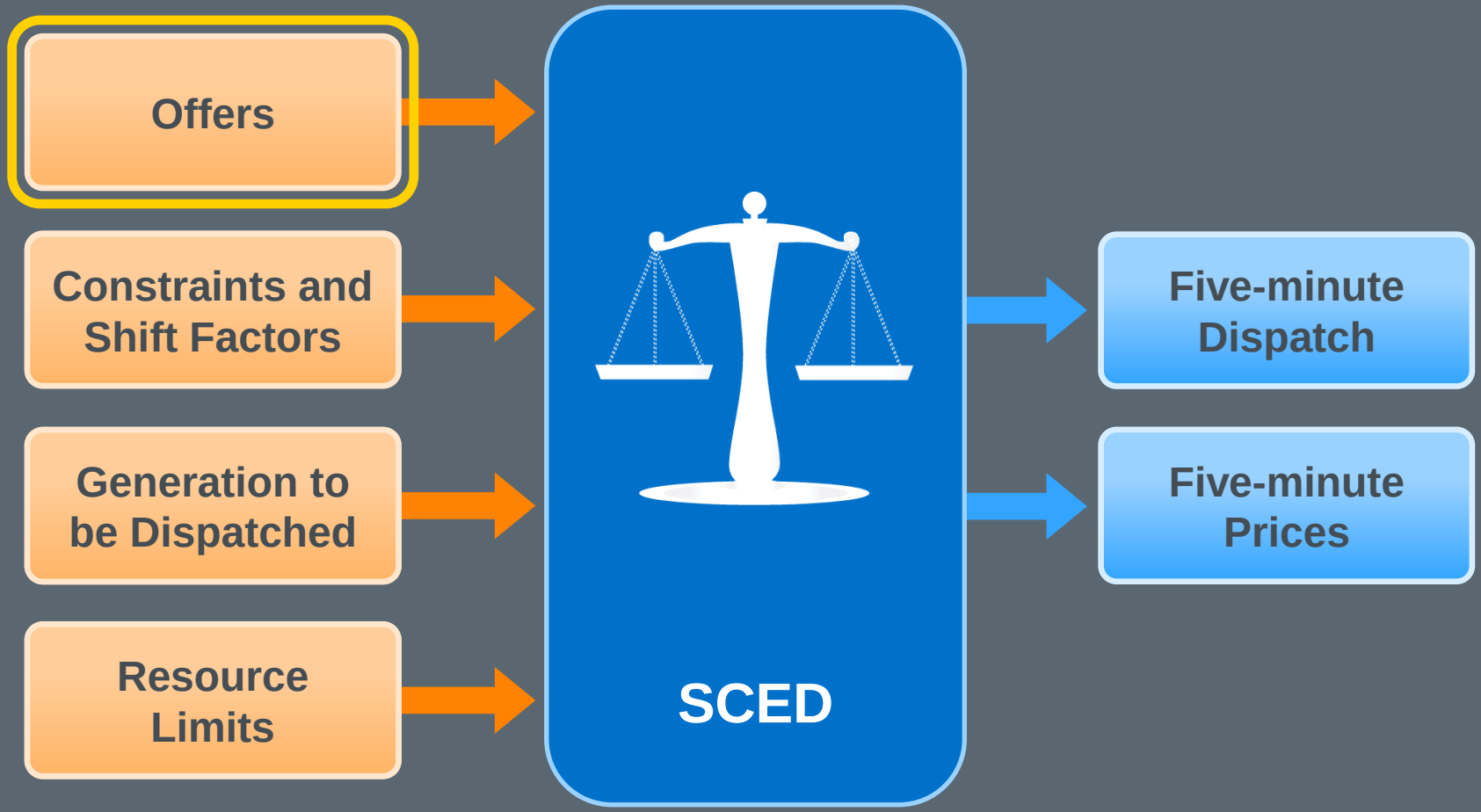
Economically optimized subject to constraints

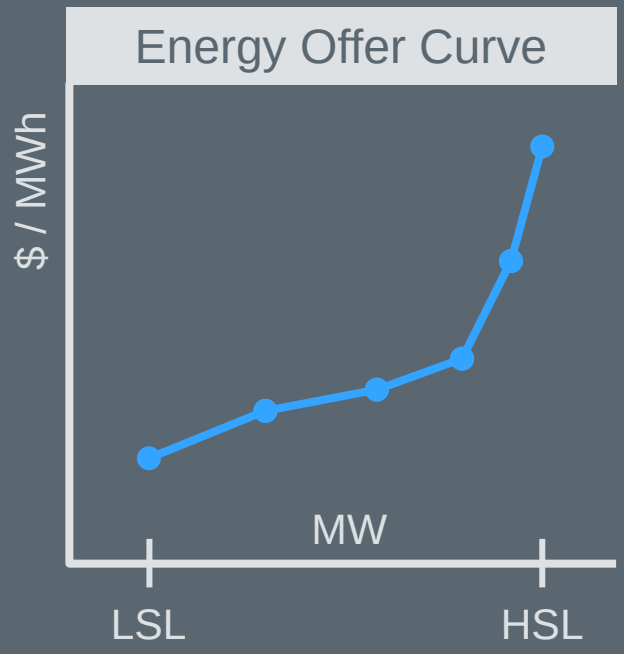


Constraints Enforced by SCED

Type	Constraints
Network Security	Power Balance Constraint
	Transmission Constraint
Resource	Dispatch Limits

Economically optimized subject to constraints

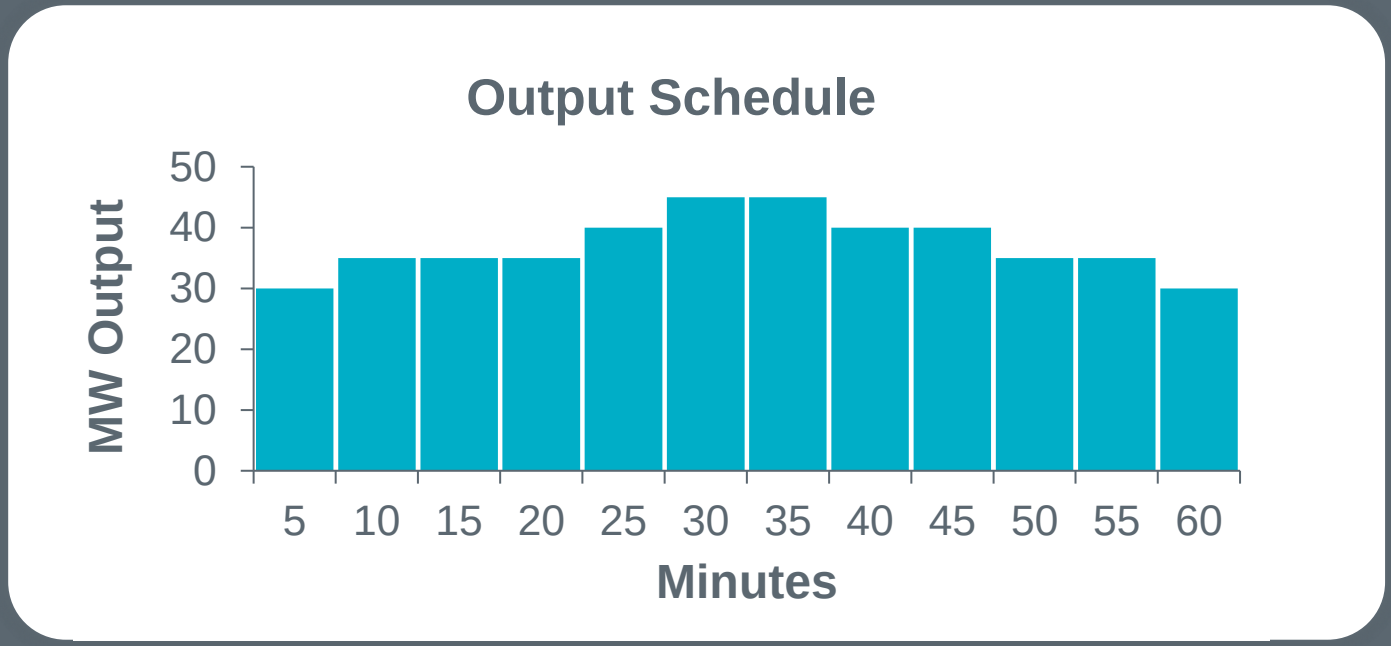




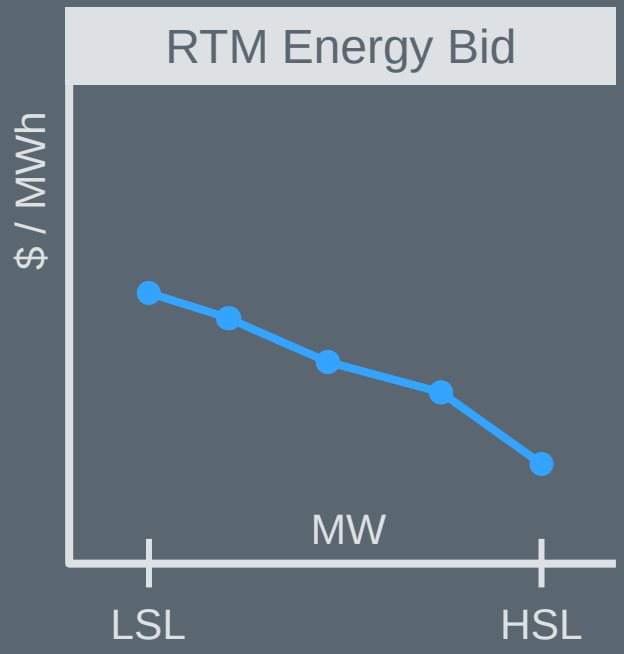
Submitted for:

- Online Resource
- Quick Start Generation Resource (QSGR)
- Offline Resource providing Non-Spin

Resource will be a Price Taker



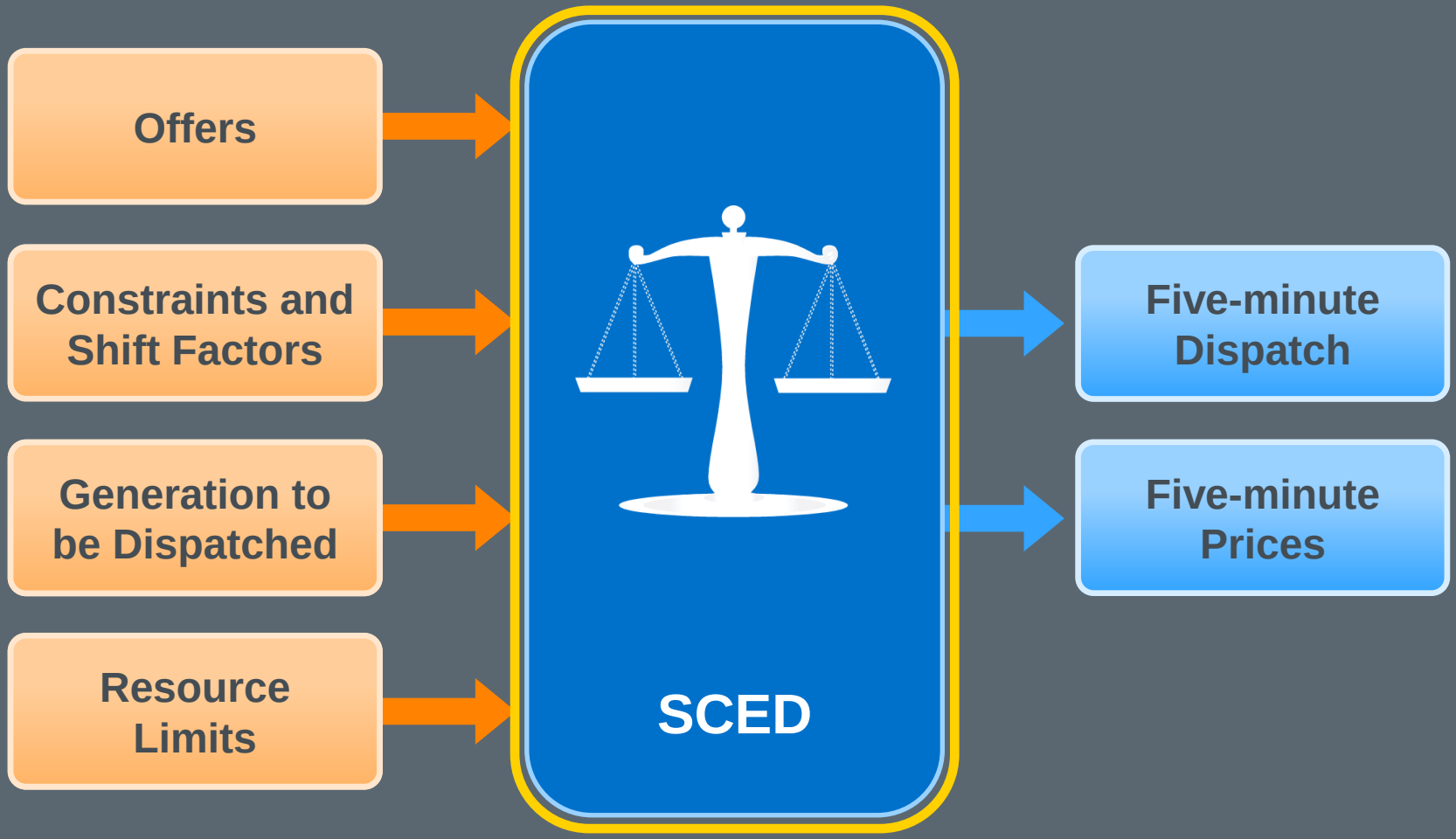
Load Resource “Offers”



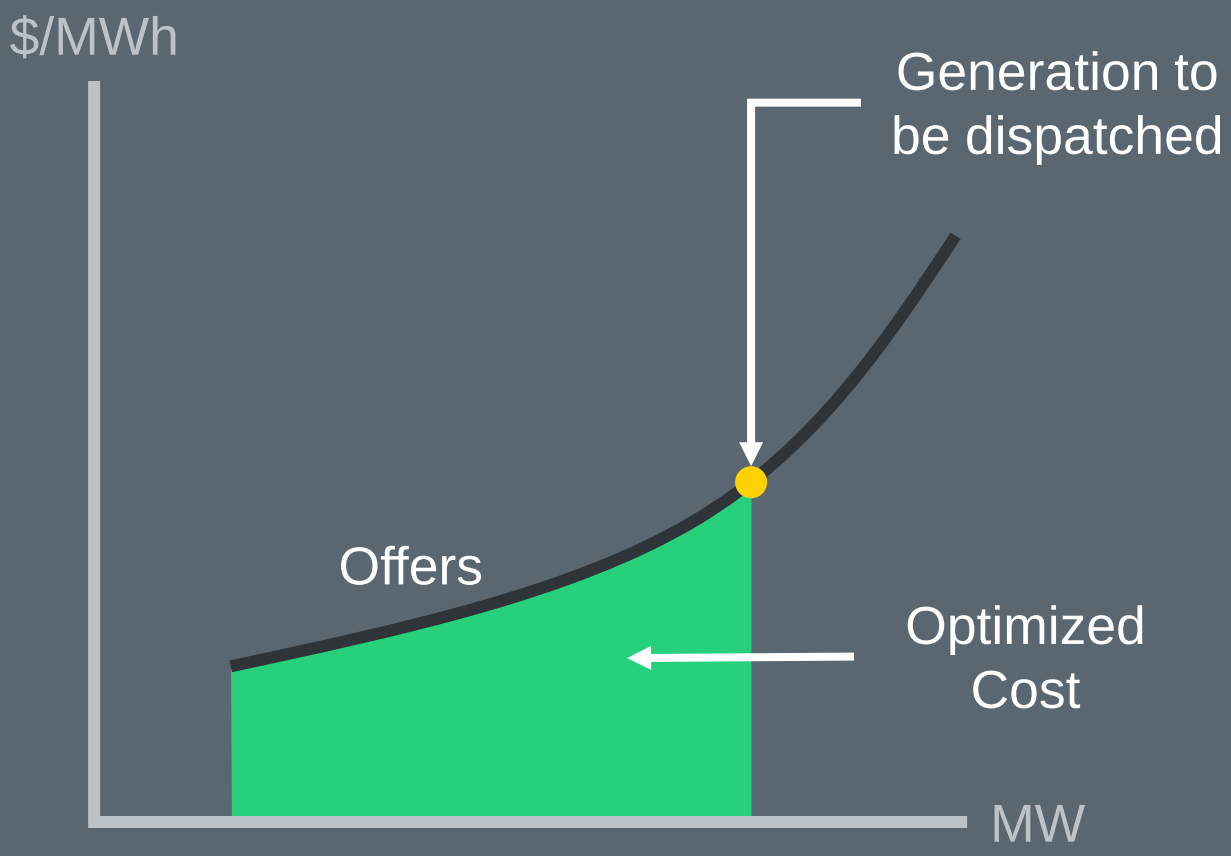
Submitted for:

- Controllable Load Resource
- Aggregate Load Resource
- Energy Storage Resource

Economically optimized subject to constraints



Minimize Dispatch Costs



SCED Optimization calculates Shadow Prices

- SP_{demand} for the Power Balance Constraint
- SP_c for each Transmission Constraint

Locational Marginal Prices for Energy

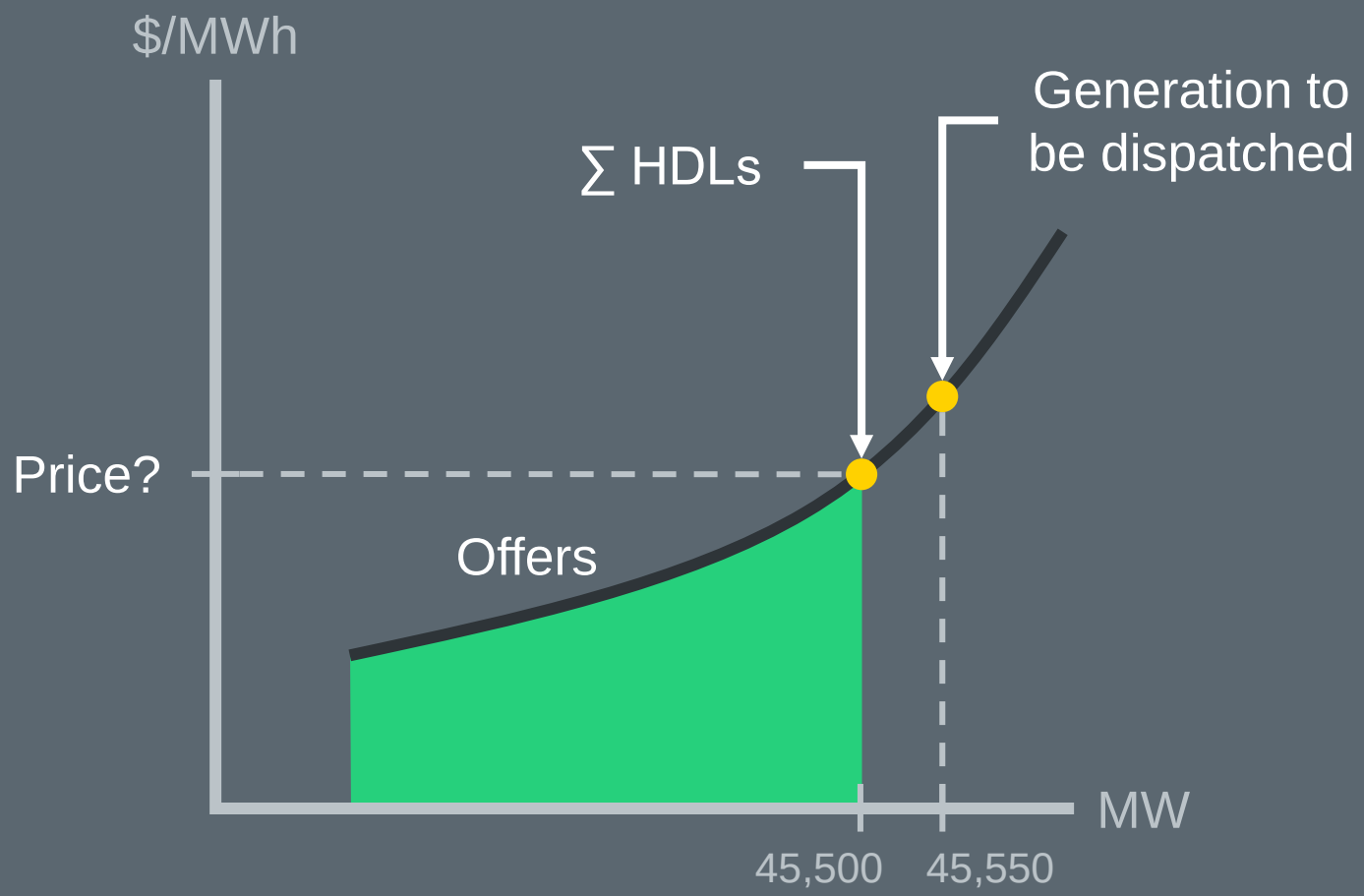
$$LMP_{bus} = SP_{demand} - \sum_{c} SF_{bus,c} * SP_c$$

Shift Factor of the bus on Transmission Constraint “c”

Also known as System Lambda (λ)

SCED Shadow Prices subject to caps

What is SCED going to do?



Sets SP_{demand} when SCED violates Power Balance

Under-Generation

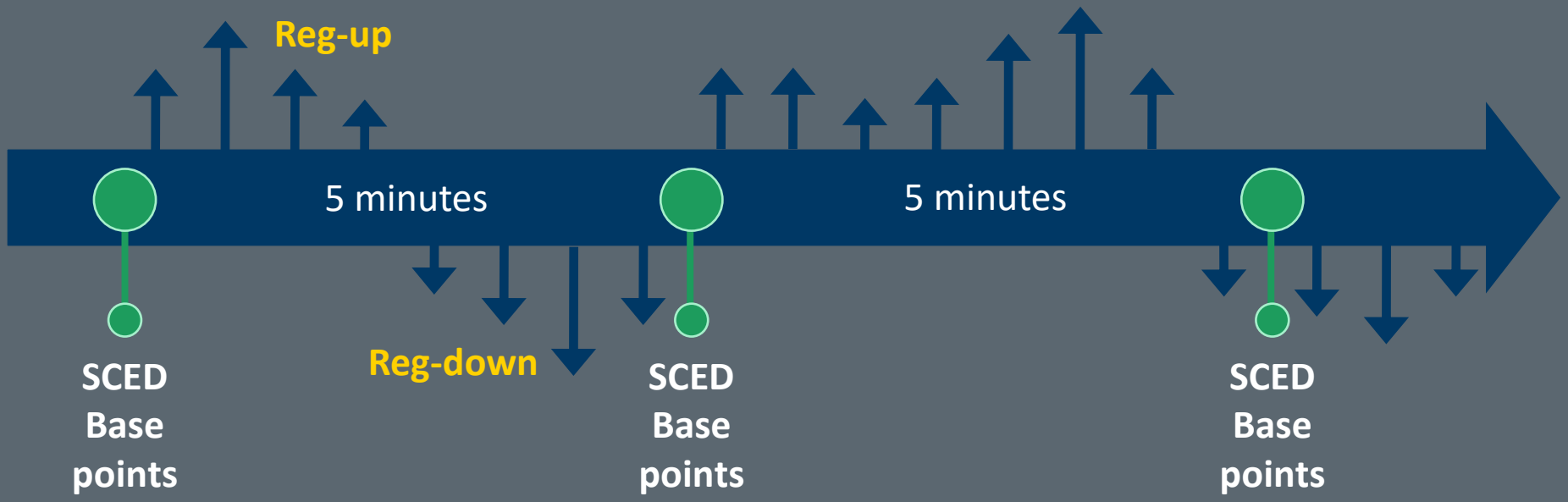
MW Violation	$/MWh
MW ≤ 5	250
5 < MW ≤ 10	300
10 < MW ≤ 20	400
20 < MW ≤ 30	500
30 < MW ≤ 40	1000
40 < MW ≤ 50	2250
50 < MW ≤ 100	4500
MW > 100	5001

Over-Generation

MW Violation	$/MWh
MW < 100,000	-250

Power Balance Violations

Any Power Balance violation by SCED will be covered by Regulation

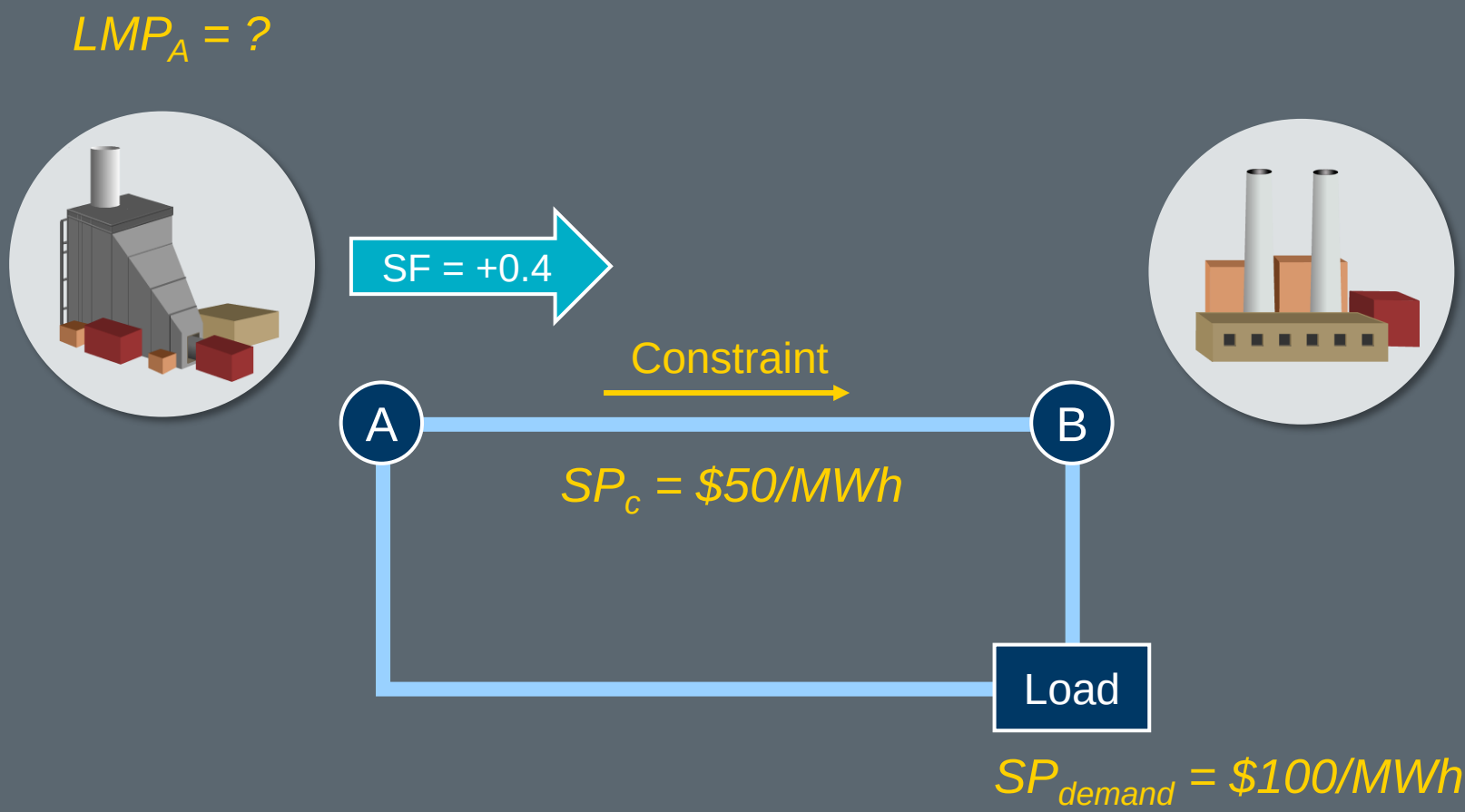


SCED will violate constraint whose cap is reached

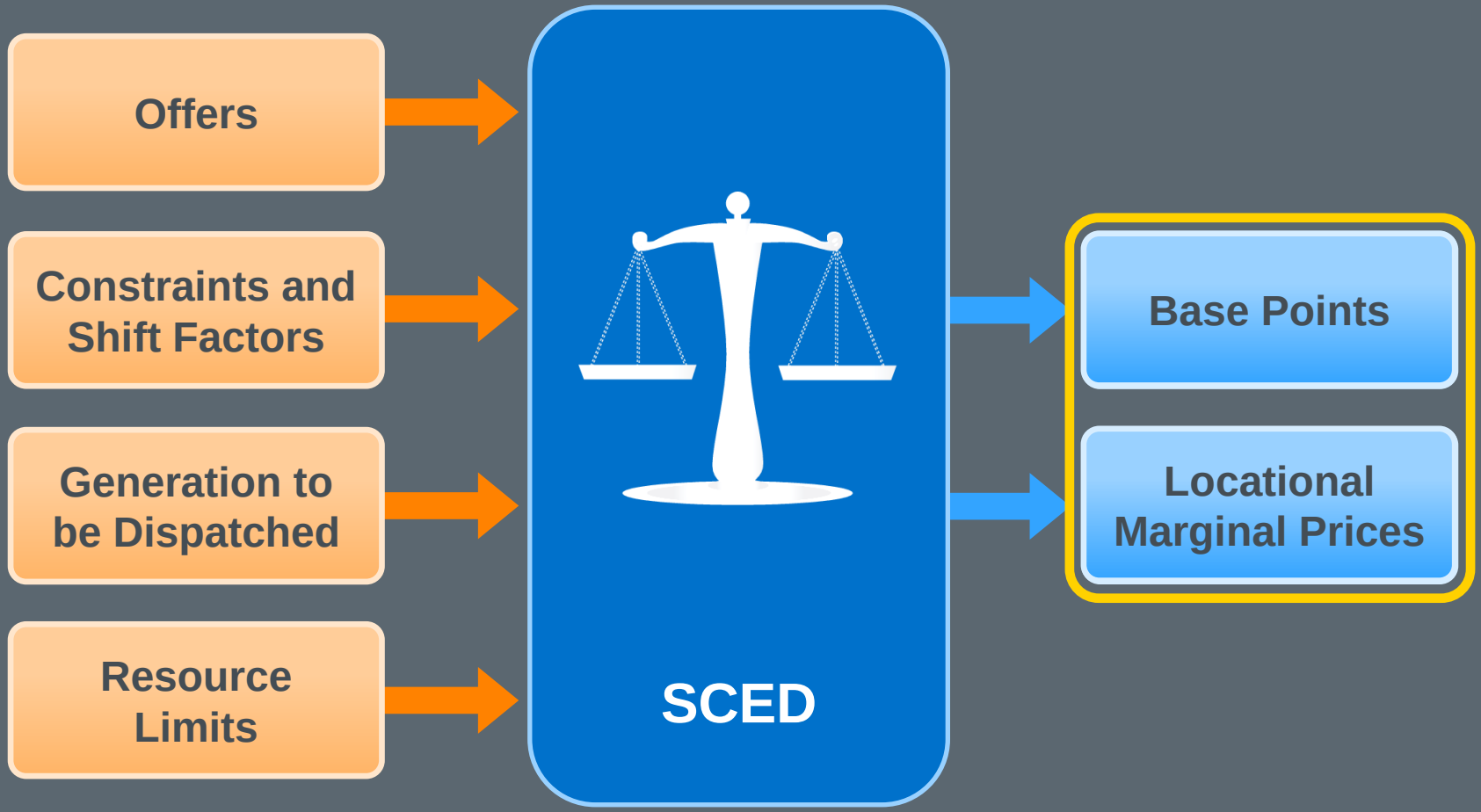
Type of Constraint	Transmission Voltage	SP_c Cap ($/MWh)
Base Case	N/A	5251
N-1 Constraint	Voltage < 100kV	2800
	100kV ≤ Voltage ≤ 200kV	3500
	200kV < Voltage	4500

Impact to LMPs depends on Shift Factors

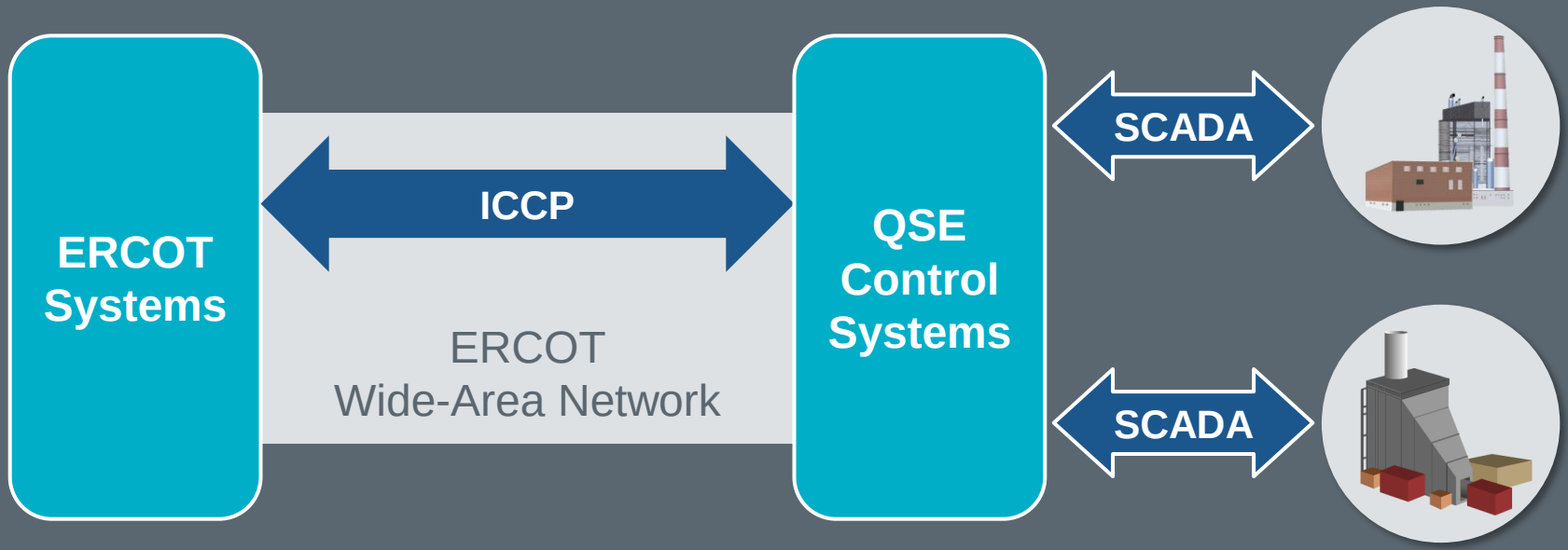
Discussion: Shadow Prices and Resource Node LMPs



Economically optimized subject to constraints



Resource-specific Base Points sent to QSEs

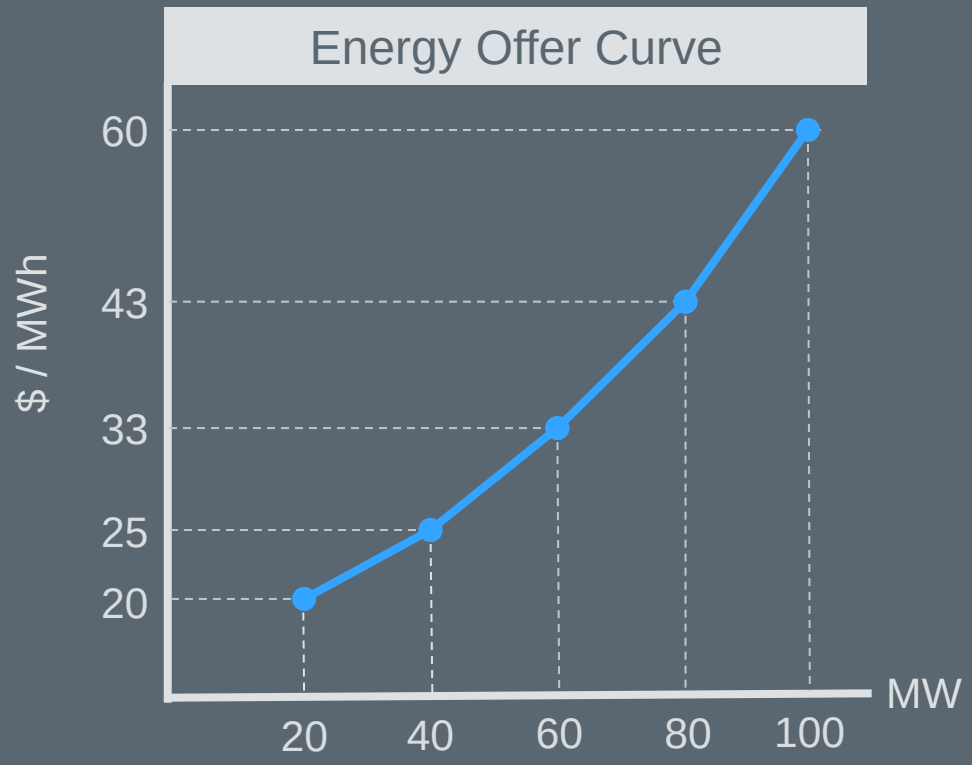


A Generation Resource is available for SCED dispatch

SCED runs at 1100 and dispatches the Resource to 80MW @$43.

SCED runs at 1105 and dispatches Resource to 55MW @ -$1000

What is happening?



Resource Reserve Deployment in Real-Time

1. Load Frequency Control & Primary Frequency Response
2. Ancillary Service Limits
3. Ancillary Service Deployment Methodologies

Load Frequency Control

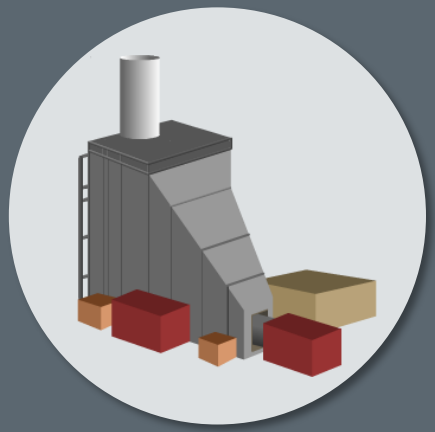
- Maintains system frequency, by
- Increasing/decreasing real power output,
- Without cost optimization

Primary Frequency Response

- Stabilizes system frequency, by
- Increasing/decreasing real power output,
- Without cost optimization

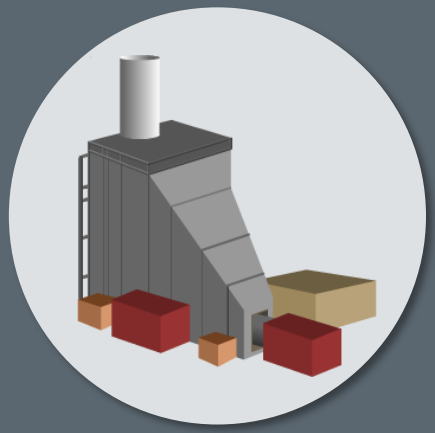
The following units must have Governor systems:

- Generation Resources
- Settlement Only Transmission Generators
- Settlement Only Transmission Self-Generators
- Controllable Load Resources

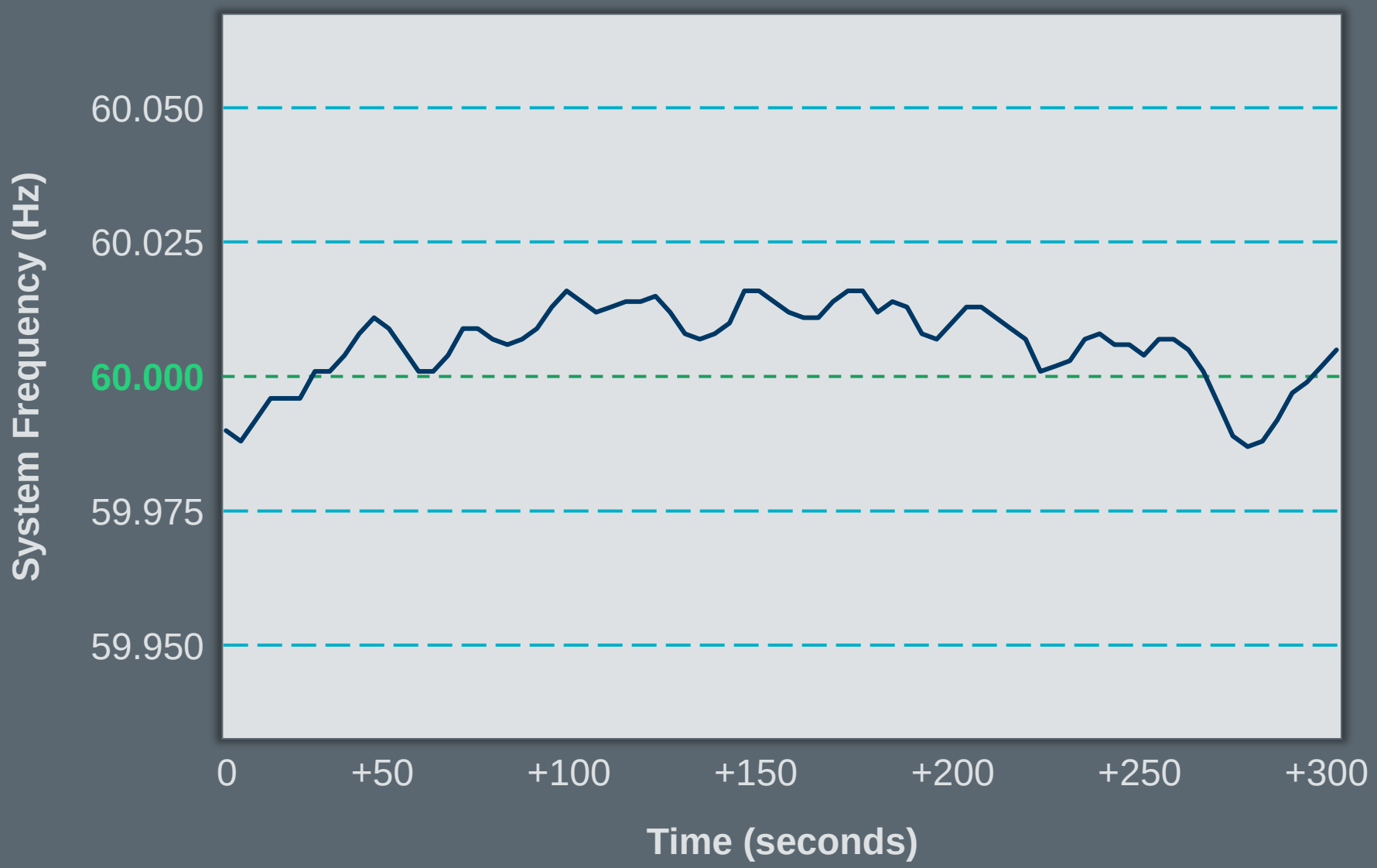


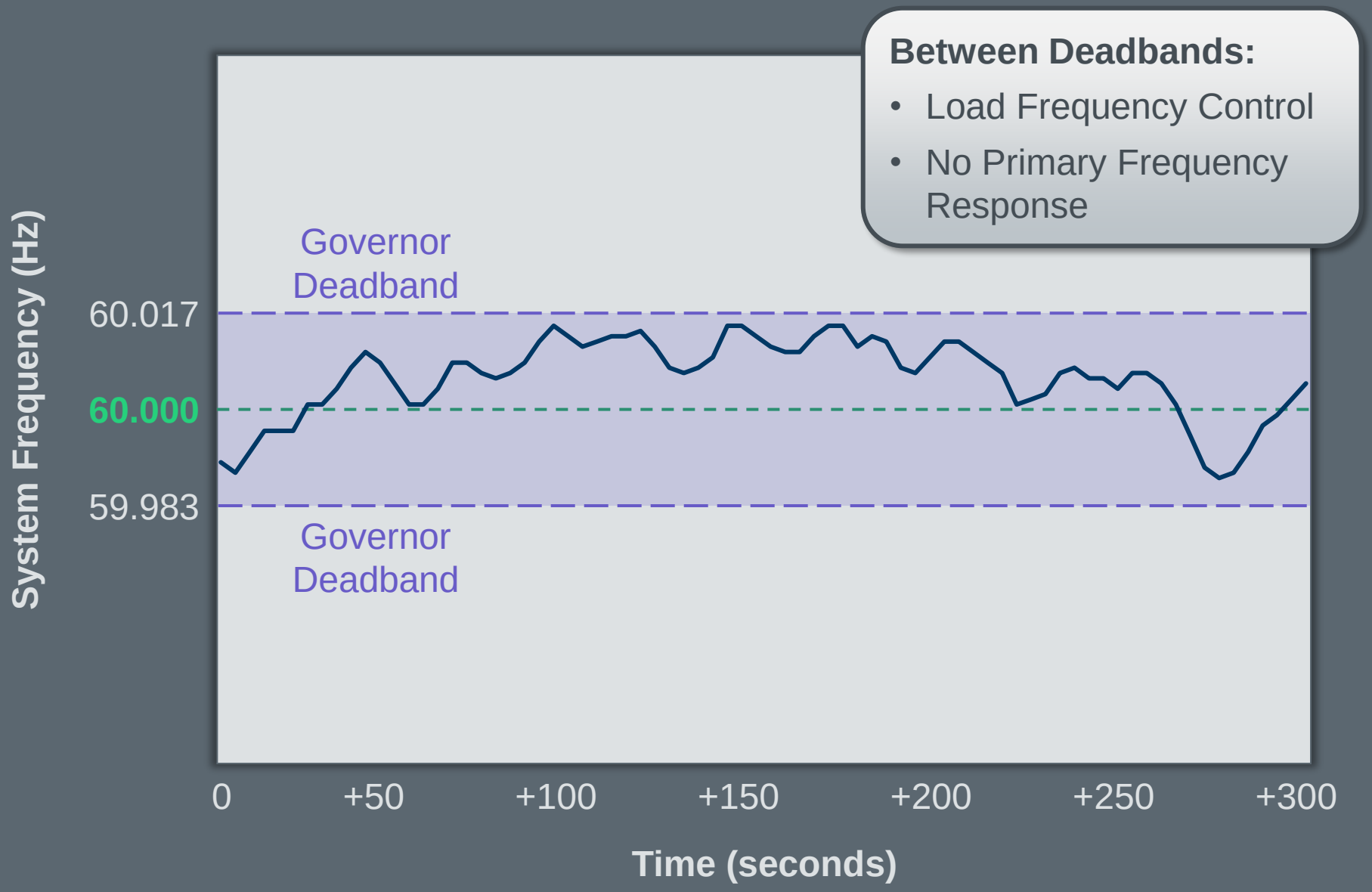
Governors must respond to changes in system frequency

. . . after a point

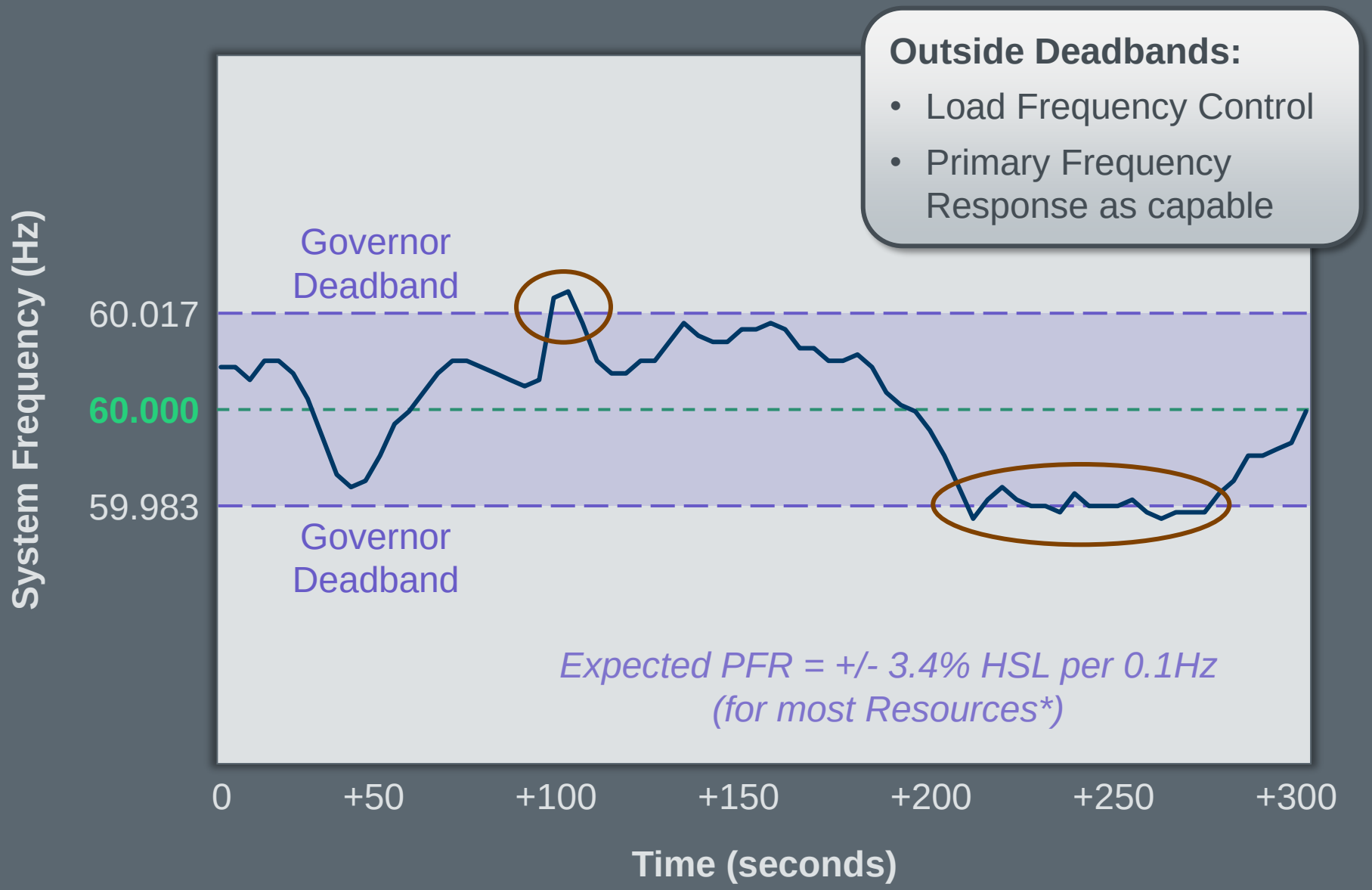


Control of System Frequency



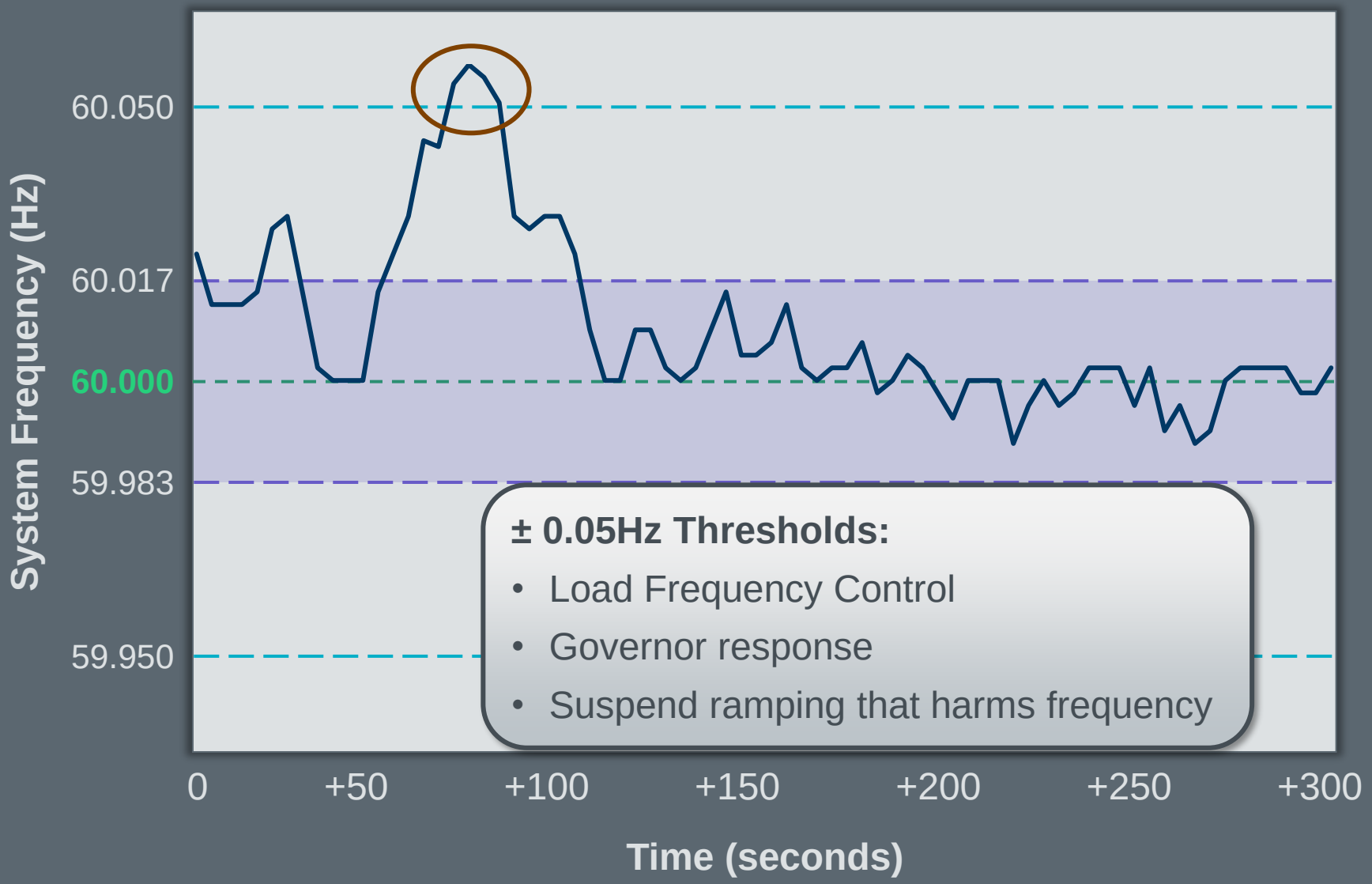

Between Deadbands:
• Load Frequency Control
• No Primary Frequency Response
Governor Deadband
60.017
60.000
59.983
Governor Deadband
System Frequency (Hz)
0
+50
+100
+150
+200
+250
+300
Time (seconds)

Control of System Frequency

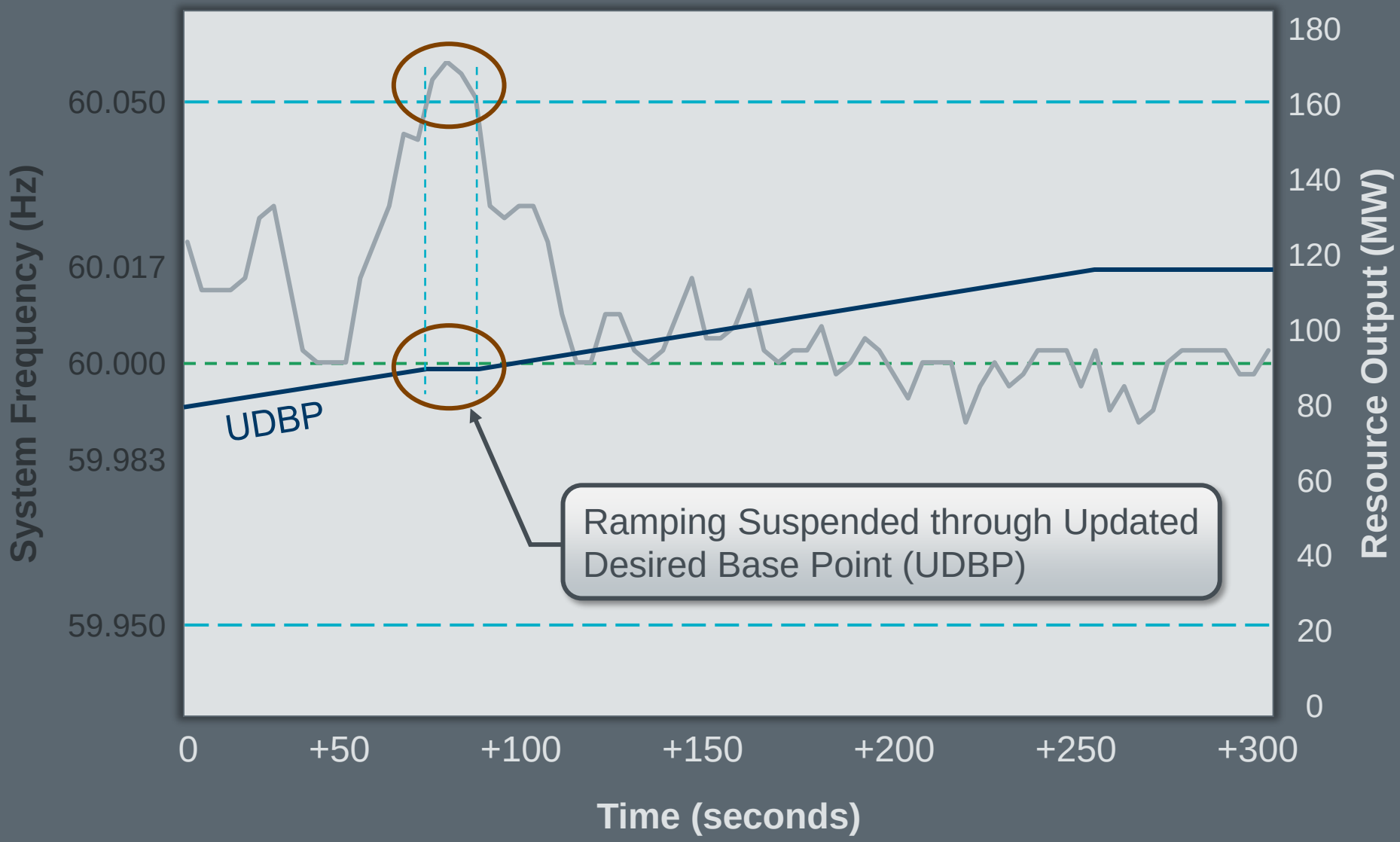


* See Nodal Operating Guide Sections 2 and 8 for more details

Control of System Frequency

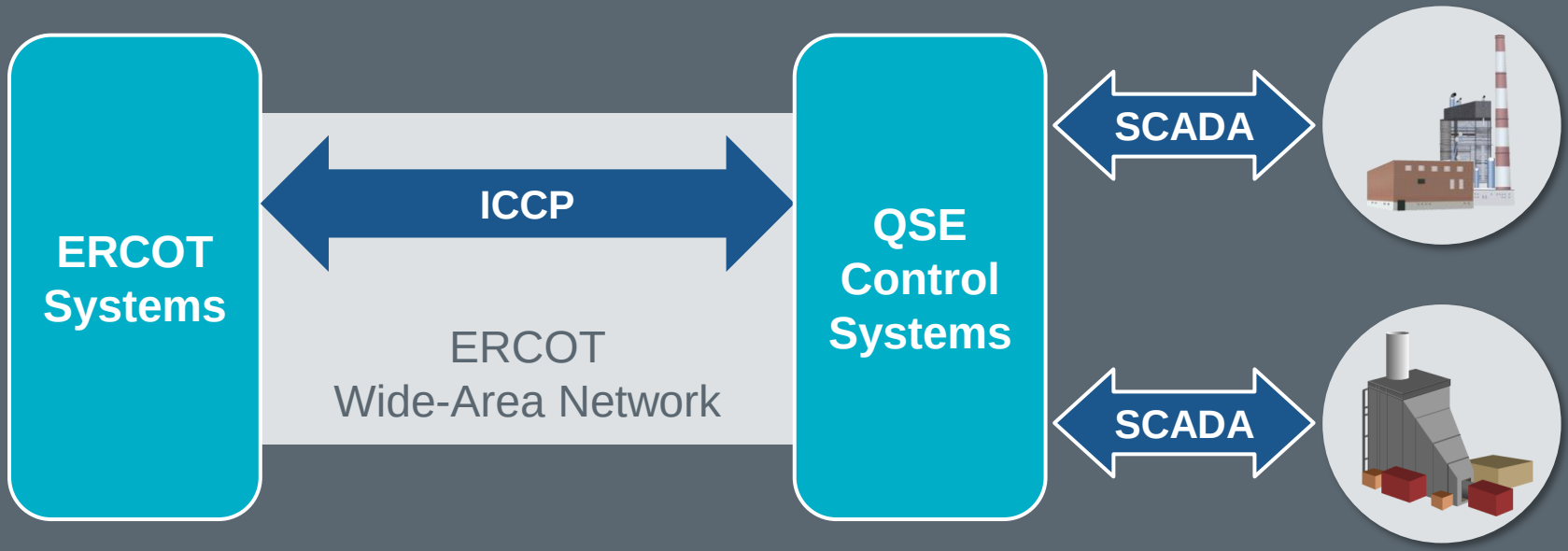


Ramping suspension



UDBPs sent to QSEs every 4 seconds

- Expected MW output
- Does not include Regulation



1 Load Frequency Control & Primary Frequency Response

2 Ancillary Service Limits

3 Ancillary Service Deployment Methodologies

Limits enforced in Real-Time:

Generation Resources	Responsive Reserve (RRSPF subtype)	≤ RRSPF% of HSL (20% or Proven)
	Responsive Reserve (RRSFF subtype)	≤ 15-minute capacity
	ERCOT Contingency Reserve Service (ECRS)	≤ 10 * Emergency Ramp Rate
Hydro as Synchronous Condenser	Responsive Reserve ≤ 20 second capability	
All Resources	LSL + Non-Spin + ECRS + Responsive + Reg-Up ≤ HSL	

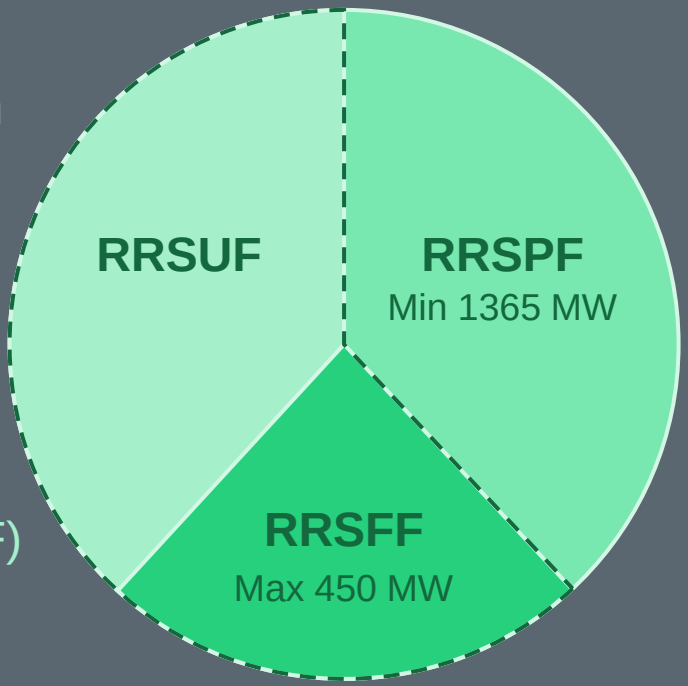
Fast Responding Regulation Service

Fast Responding Regulation Up	System total capped at 65 MW
Fast Responding Regulation Down	System total capped at 35 MW

Responsive Reserve Service Subtypes

Load Resource on Under-Frequency Relay

Max (RRSUF + RRSFF) = 60 % Total RRS



Primary Frequency Response

Fast Frequency Response

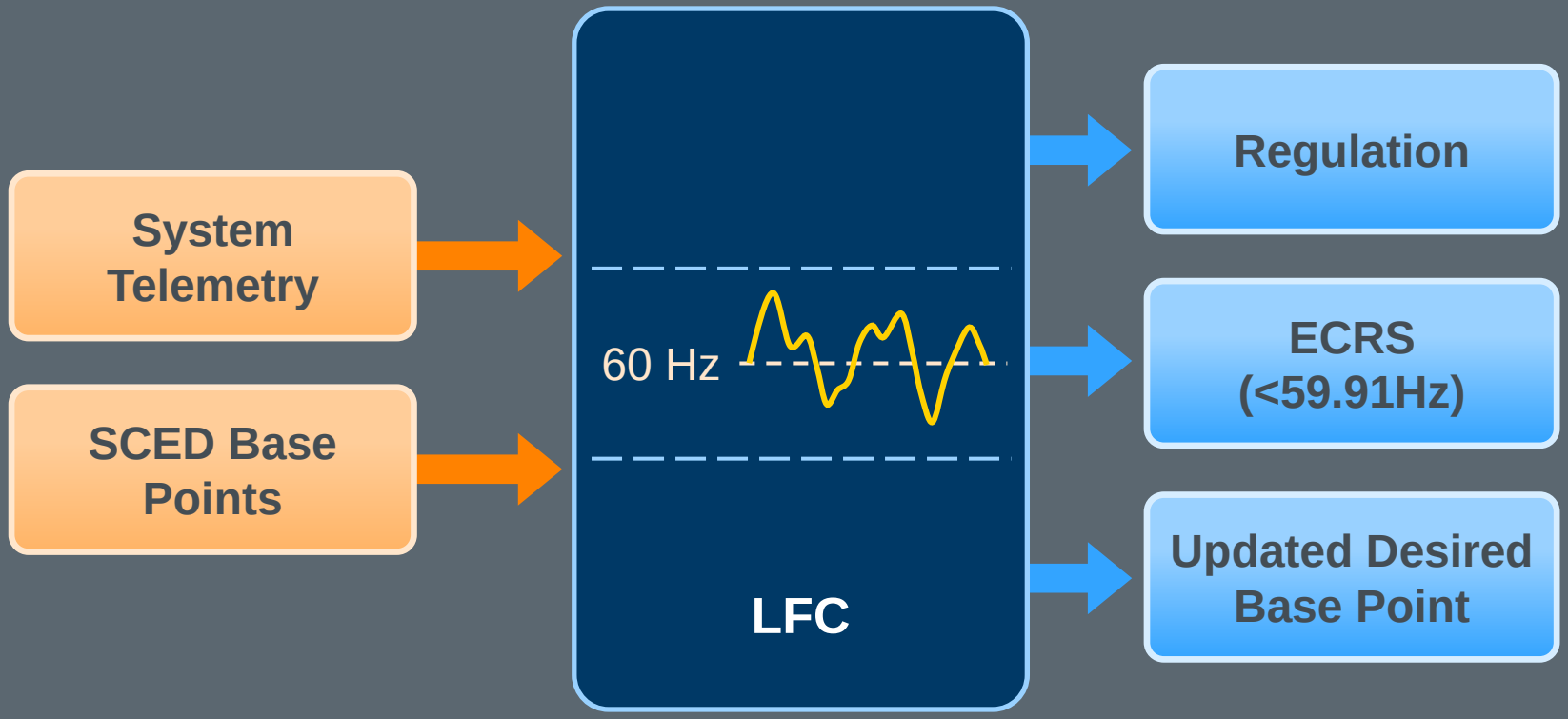
1 Load Frequency Control & Primary Frequency Response

2 Ancillary Service Limits

3 Ancillary Service Deployment Methodologies

Methodology Varies by Service

AS Type	Deployment Methodology
Regulation Service	Load Frequency Control
Responsive Reserve Service (RRS)	Frequency Trigger
ERCOT Contingency Reserve Service (ECRS)	Operator Dispatch Instruction Load Frequency Control
Non-Spinning Reserve Service (NSRS)	Operator Dispatch Instruction Standing Deployment



Runs every 4 seconds!

Regulation Service

Proportional by QSE Share

- Not Resource-specific
- No price consideration

Must be able to ramp through reserved capacity in 5 minutes

Calculates MWs needed to correct system frequency

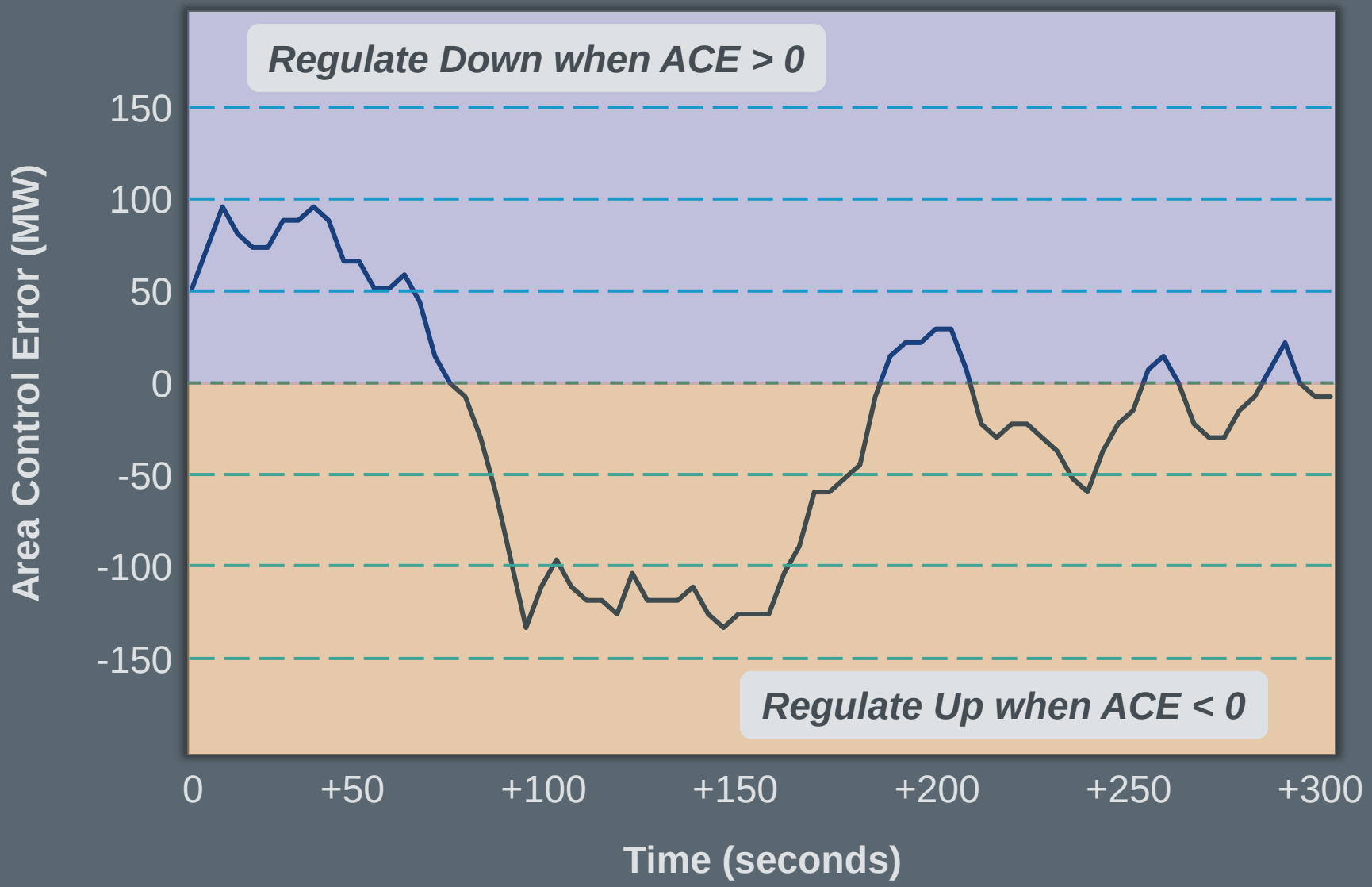
The Equation

$$\text{ERCOT ACE} = -10ß\,(F_S - F_A)$$

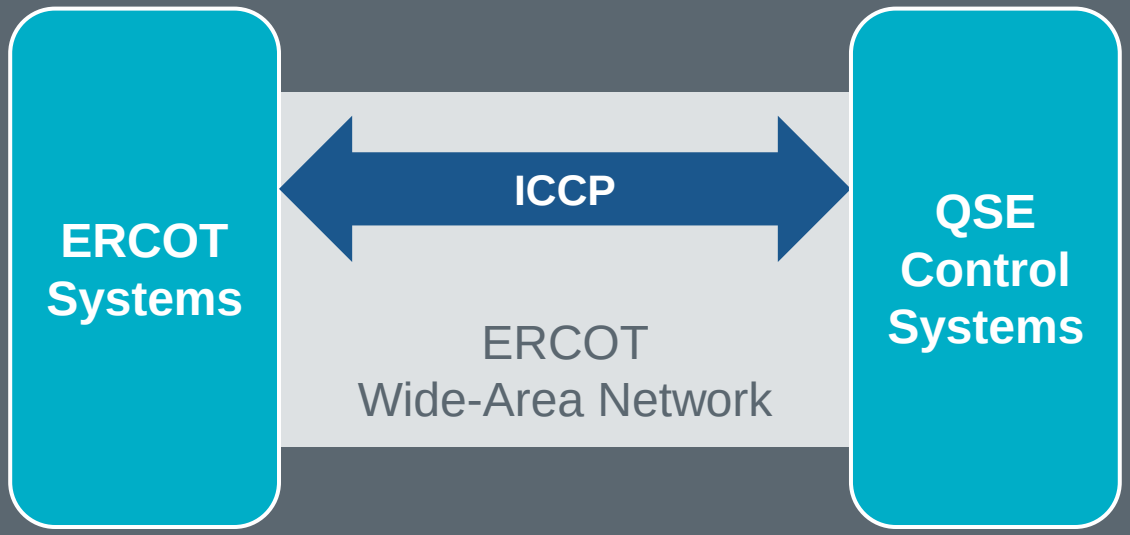
Adjusted for difference between Resources' UDBP and actual MW output

Legend	
F_S	Scheduled Frequency
F_A	Actual Frequency
ß	System Frequency Bias (MW Change per 0.1Hz)

Area Control Error (ACE)



Regulation Service Communications



ERCOT to QSEs:

- Regulation MW
- Fast Responding Regulation MW

QSEs to ERCOT:

- AS Resource Responsibility
- Participation Factors
- Raise/Lower Block Status

Two modes of deployment

By ERCOT ICCP Control Signal

- ERCOT determines MW
- Resource deploys in 60 cycles

By Frequency Trigger

- Auto deploys at +/- 0.09Hz
- Must deliver 100% in 60 cycles

ERCOT recalls when system frequency recovers

Responsive Reserve is frequency responsive

RRSPF – Primary Frequency Response

- Automatic Response at 59.983 Hz
- May be deployed manually

RRSFF – Fast Frequency Response

- Auto-deployed at 59.85 Hz
- Responds within 15 Cycles
- Sustain 15 min / Restore 15 min

RRSUF – Load Resource on UFR

- Auto-deployed at 59.70 Hz
- Trips within 30 cycles

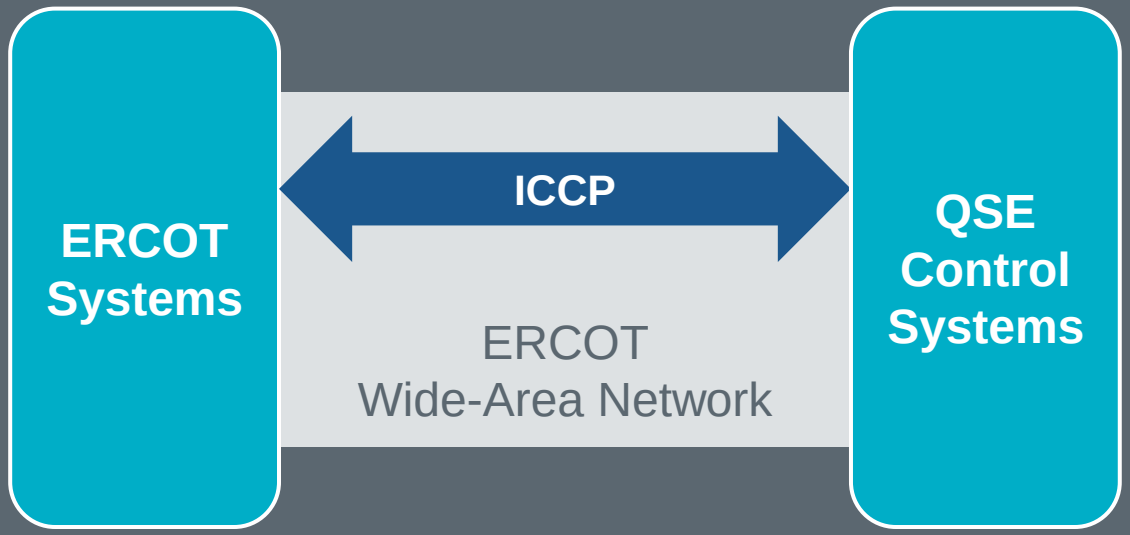
ERCOT Contingency Reserve Service

May be deployed manually or by Load Frequency Control

- Releases reserves to SCED
- Process varies by Resource Type

Must be able to ramp through reserved capacity in 10 minutes

ECRS Communications



ERCOT to QSEs:

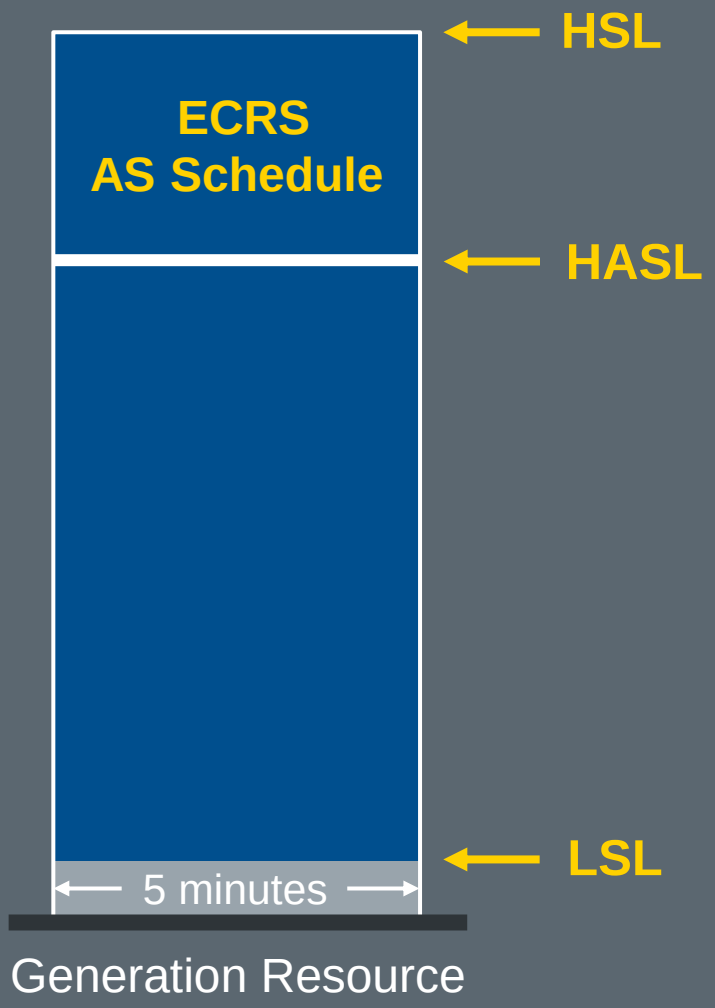
- ECRS MW
- Resource Base Point MW

QSEs to ERCOT:

- AS Resource Responsibility
- AS Schedule

Releases reserves to SCED

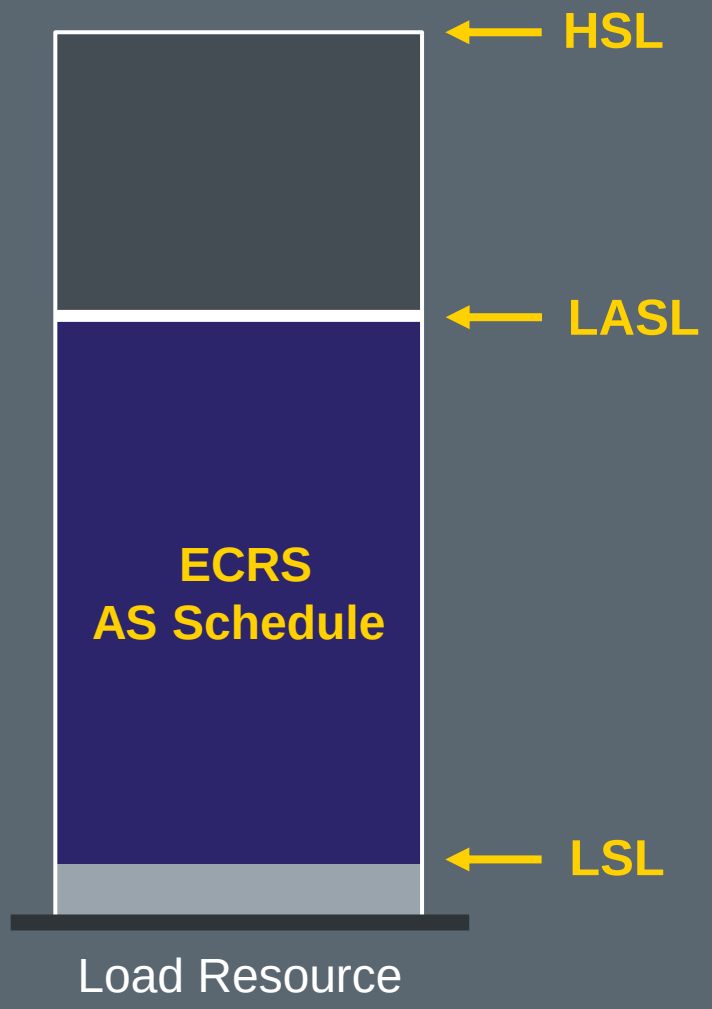
1. *ERCOT deploys ECRS*
2. *QSE reduces AS Schedule within 1 minute*
3. *ERCOT runs SCED*
4. *SCED calculates new Base Point and price*



Example: ECRS Deployment Process for Load Resources

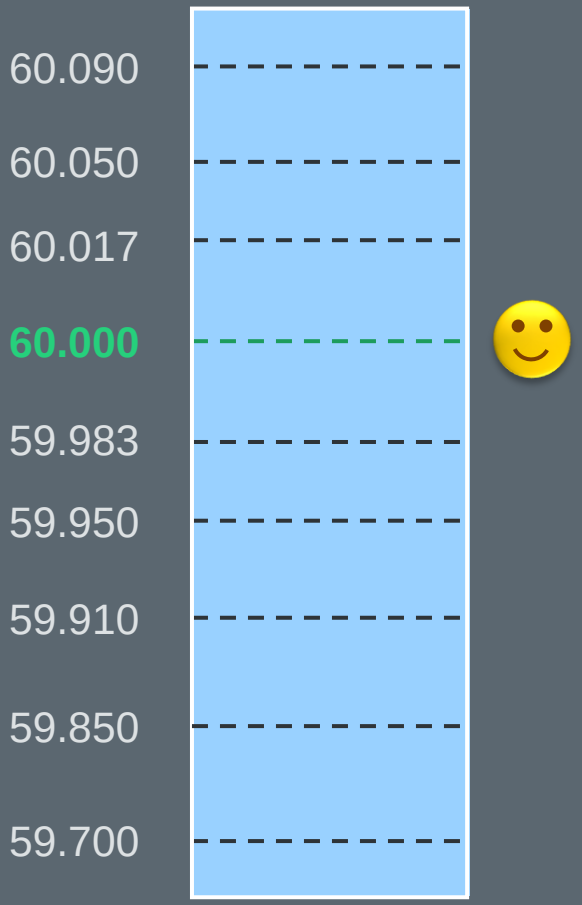
Releases reserves to system

1. *ERCOT deploys ECRS*
2. *QSE reduces AS Schedule within 1 minute*
3. *SCED calculates new CLR Base Point and Price*
4. *Non-CLR drops load within 10 minutes*



Discussion: Summary of Frequency Triggers

Name that Frequency!



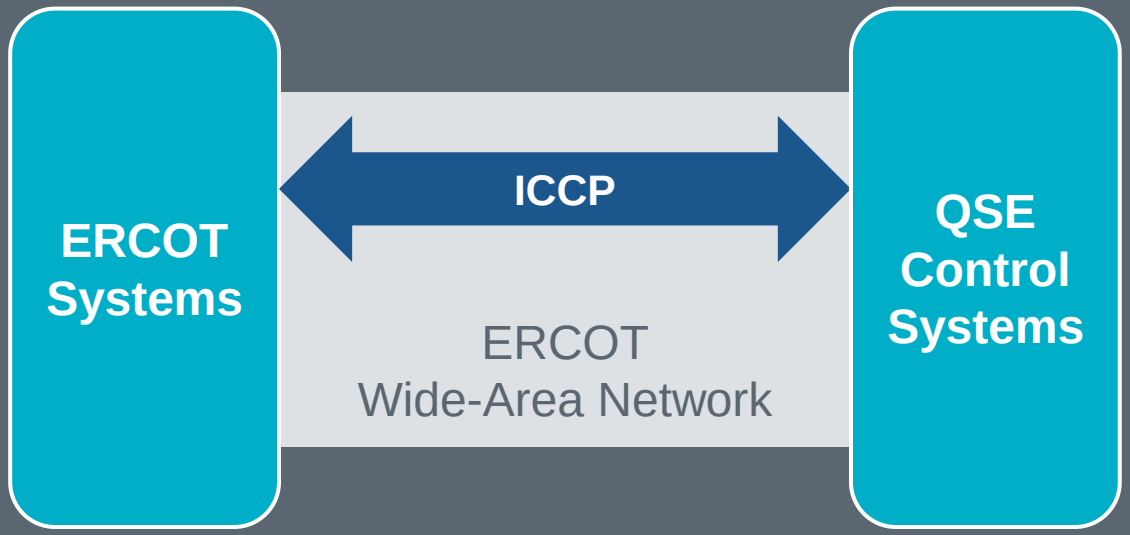
Non-Spinning Reserve Service

Resource-specific deployment

- Releases additional reserves to SCED
- Methodology varies by Resource type

Must be able to ramp through reserved capacity in 30 minutes

Non-Spinning Reserve Service Communications



ERCOT to QSEs:

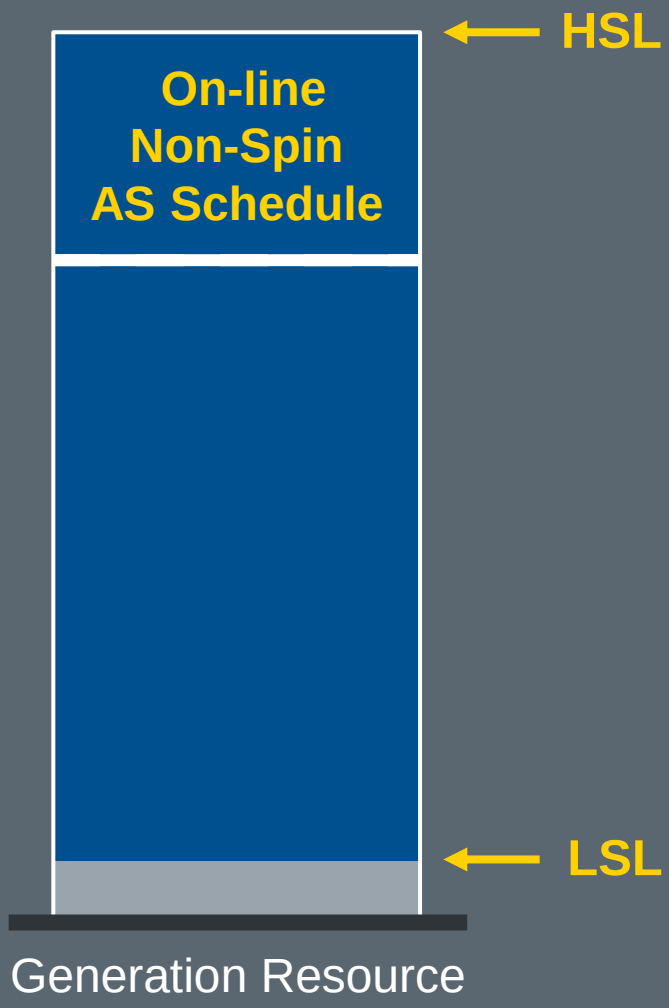
- Non-Spin Deployment
- Resource Base Point MW

QSEs to ERCOT:

- AS Resource Responsibility
- AS Schedule

Releases reserves to SCED

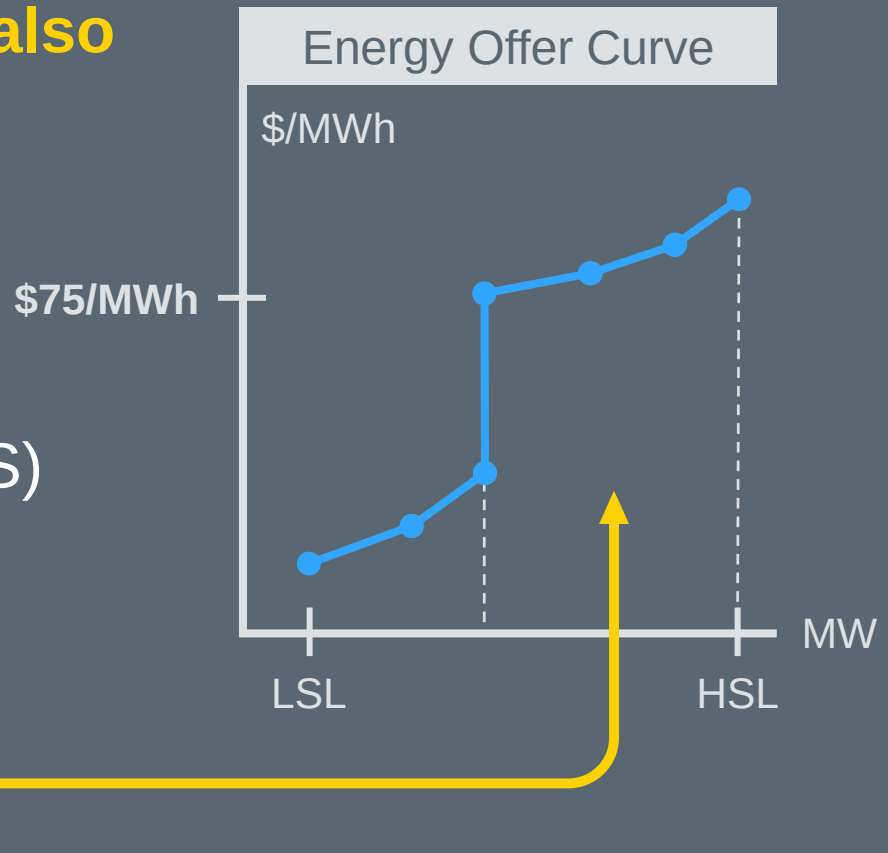
1. *QSE self-deploys at beginning of Operating Hour*
2. *Released capacity priced at or above $75/MWh*
3. *SCED will utilize if economic*



When combined with other Ancillary Services

The following products must also be priced at or above $75

- Regulation Up
- Responsive Reserve
- Contingency Reserve (ECRS)



Example: Off-Line Non-Spin Deployment Process

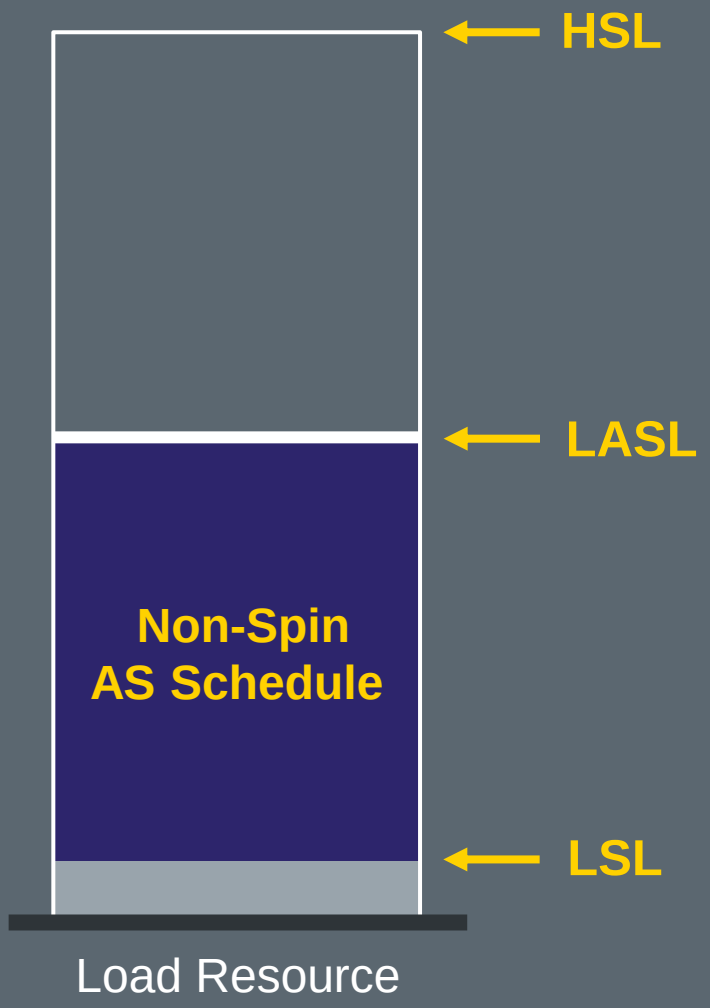
Releases reserves to SCED

1. *ERCOT Deploys Non-Spin from this Resource*
2. *QSE releases Capacity within 20 minutes*
3. *SCED dispatches according to economics*

Example: Non-Spin Deployment of Load Resources

Releases reserves to system

1. *ERCOT deploys Non-Spin*
2. *QSE releases Capacity within 1 minute*
3. *SCED dispatches CLR according to economics*
4. *Non-CLR drops load within 30 minutes*



Resources and their Financial Impacts

1. Day-Ahead Market Resource Settlement
2. Real-Time Resource Settlement
3. Settlement of RUC-Committed Resources

Payment for awarded Energy Offer

= (-1) * Awarded MWs * DASPP

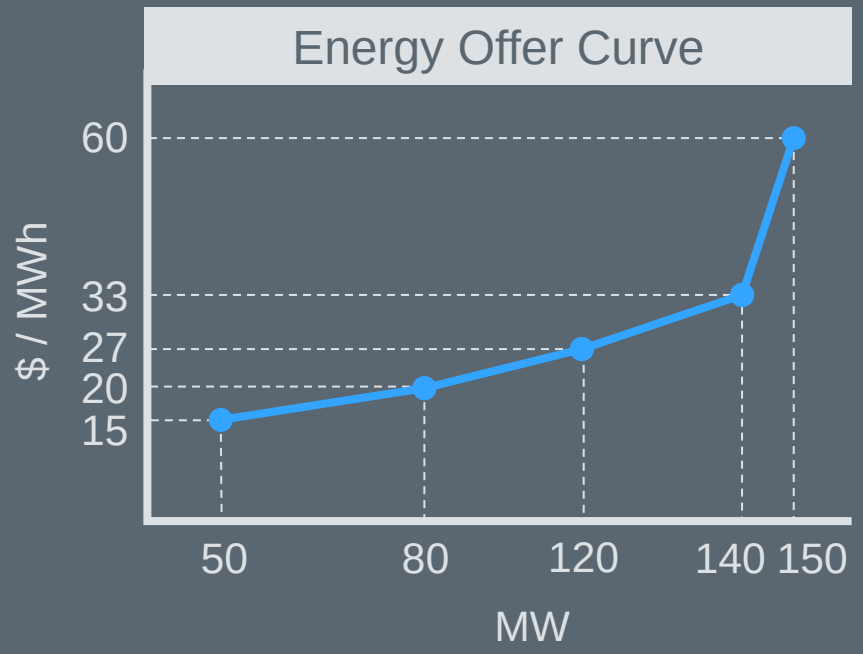
Payment for awarded Ancillary Service Offer

= (-1) * Awarded MWs * MCPC

Generation Resource BIGGEN1 is offered in DAM

- Startup Offer: $3000
- Minimum-Energy Offer: $30/MWh, LSL = 50 MW
- ECRS Offer: 10MW @ $10/MW

Assume Startup and Minimum-Energy Offers are at costs



Generation Resource BIGGEN1 is awarded for 4 hours

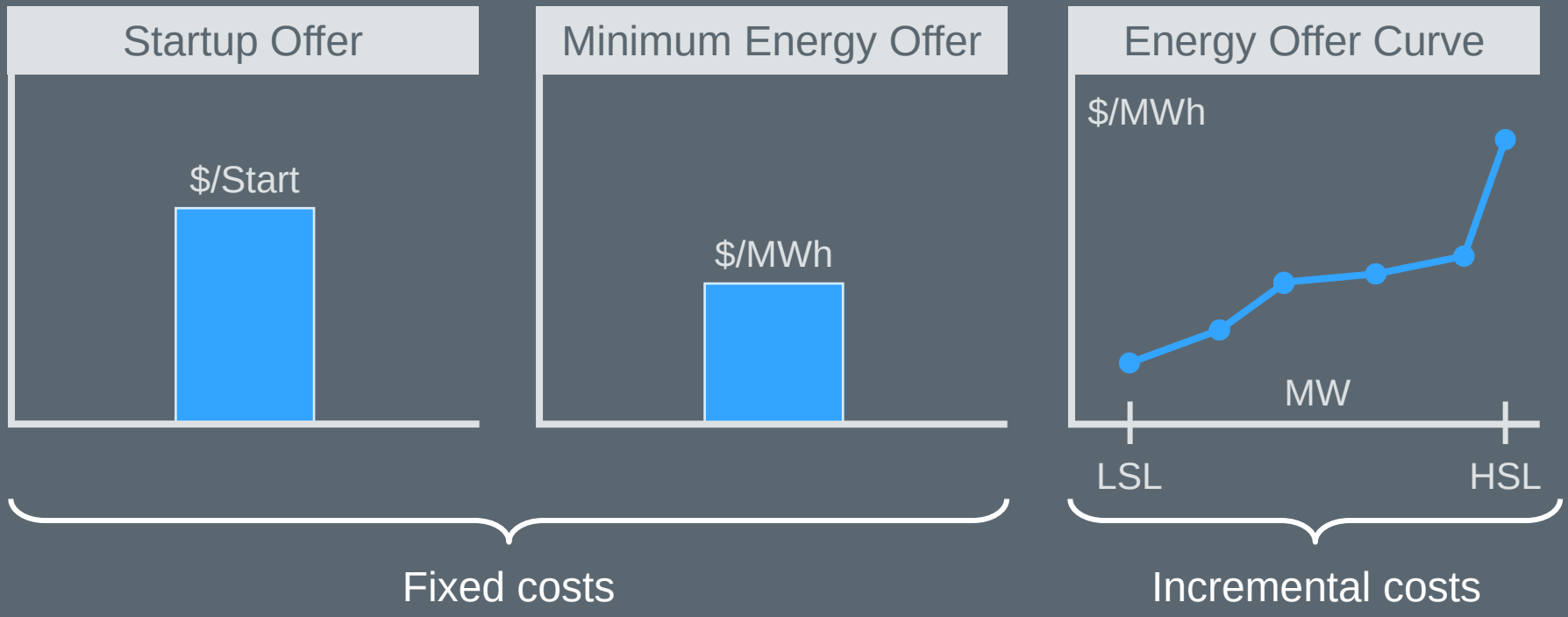
- Energy Award: 80MW @ $20
- ECRS Award: 10MW @ $10

Total Revenue = $6800

Does that cover their costs?

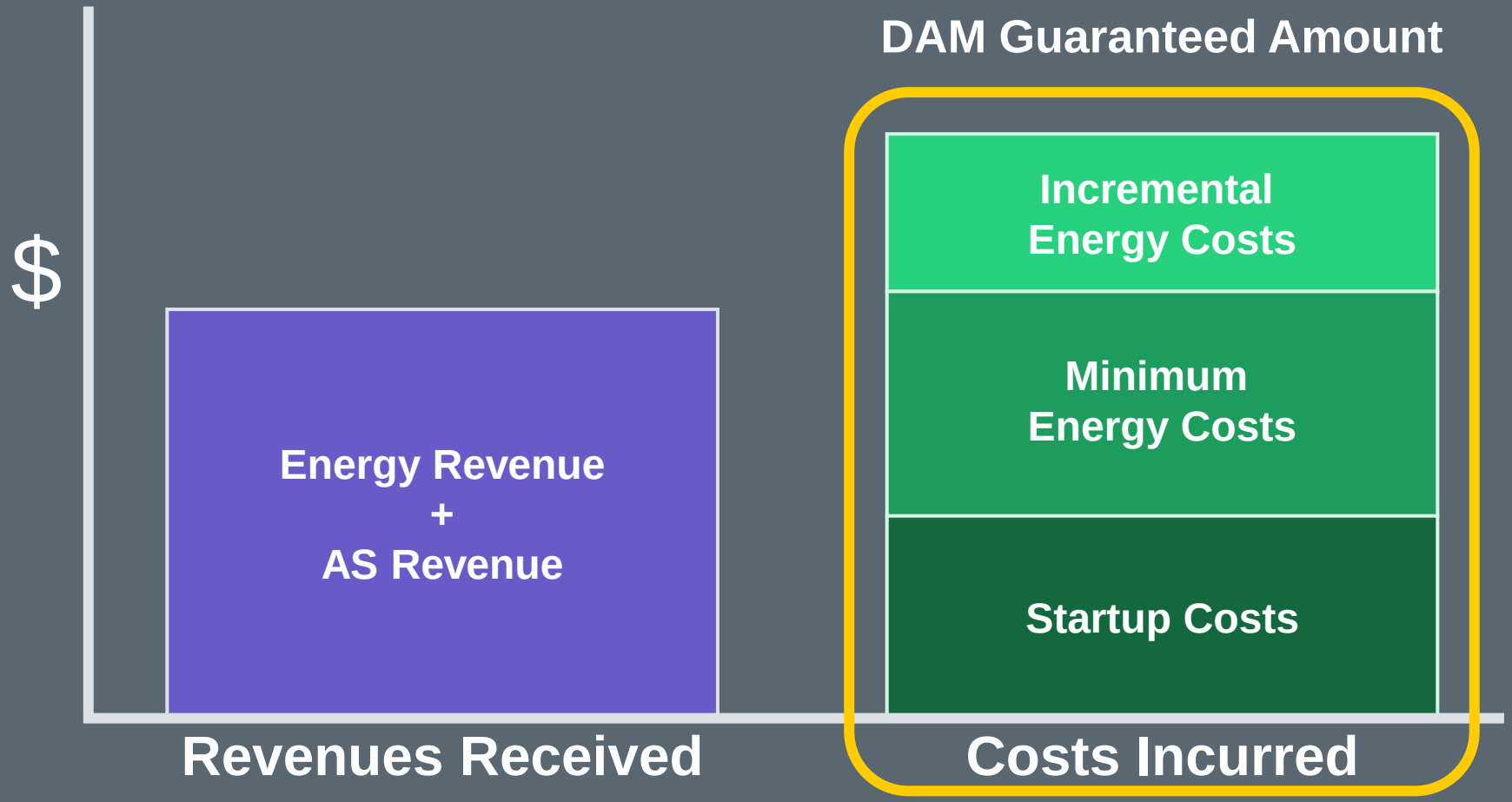
	Energy Revenue	AS Revenue
Hour 1	$1600	$100
Hour 2	$1600	$100
Hour 3	$1600	$100
Hour 4	$1600	$100
Total	$6400	$400

What Happened?



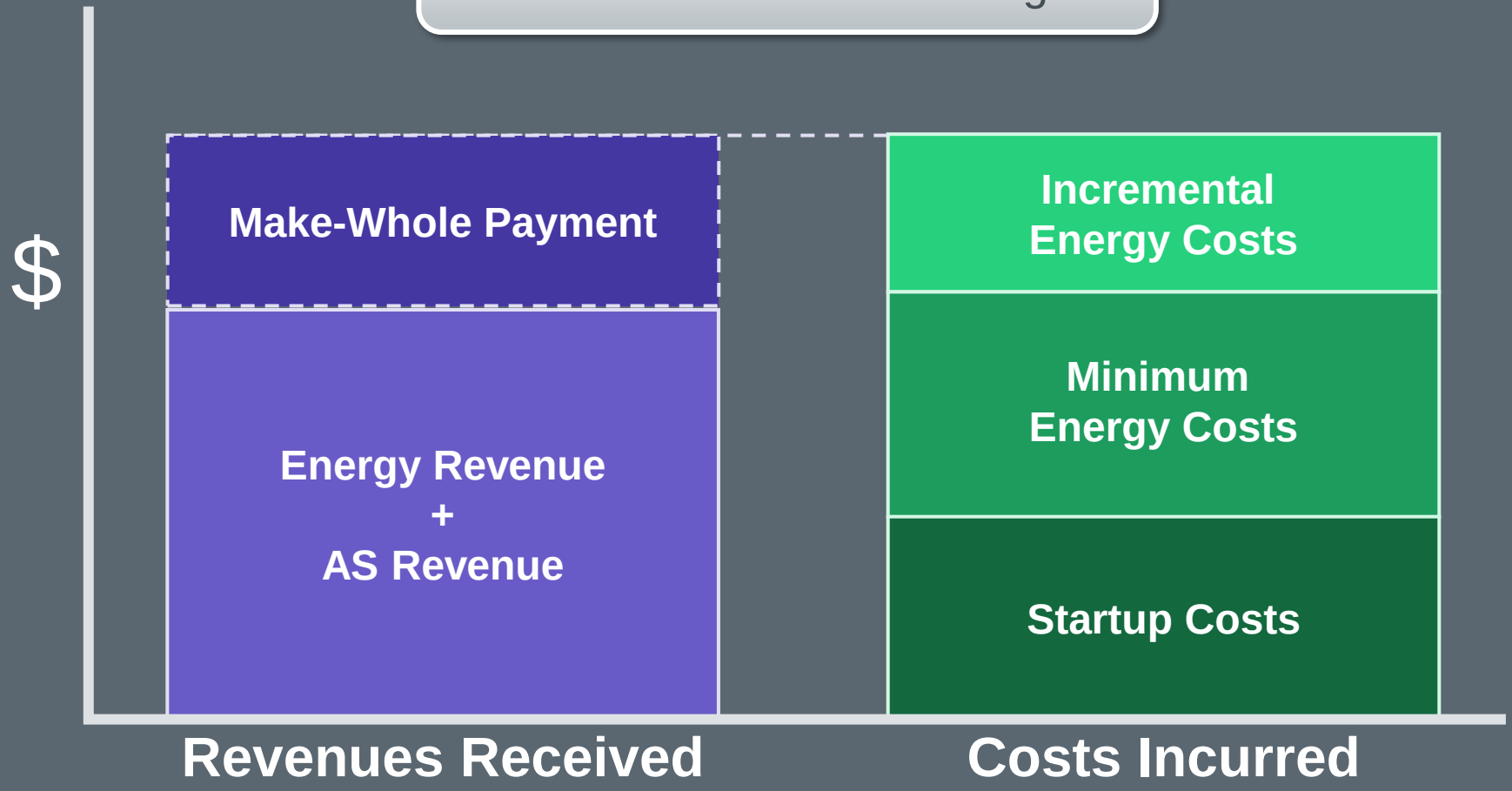
LMPs are determined from incremental costs

Day-Ahead Make-Whole Payment



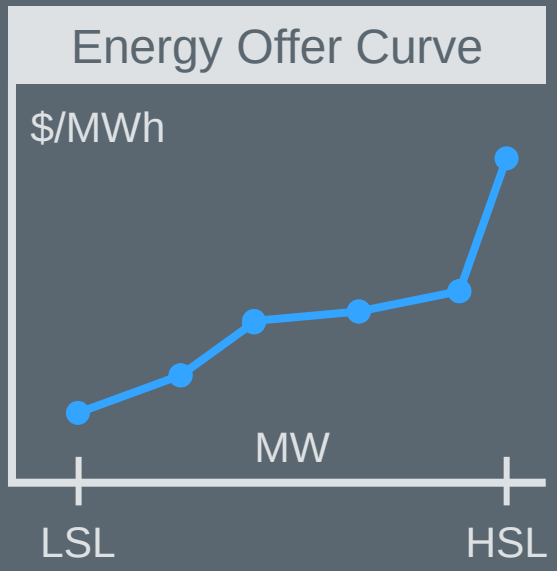
Day-Ahead Make-Whole Payment

Resource must run to be eligible



Make-Whole costs are capped

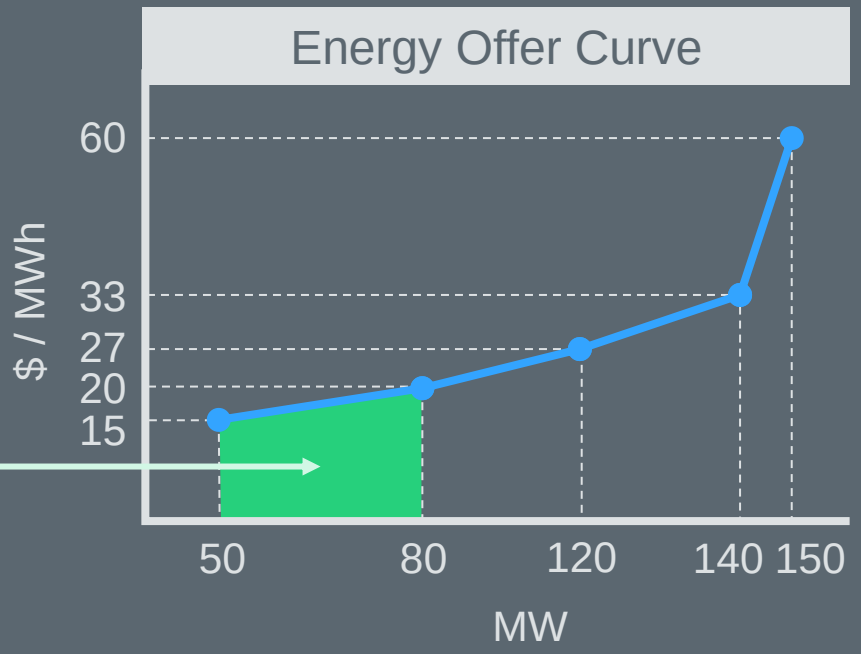
- Generic Costs from Protocols
- Approved Verifiable Costs for Start-up and Minimum Energy



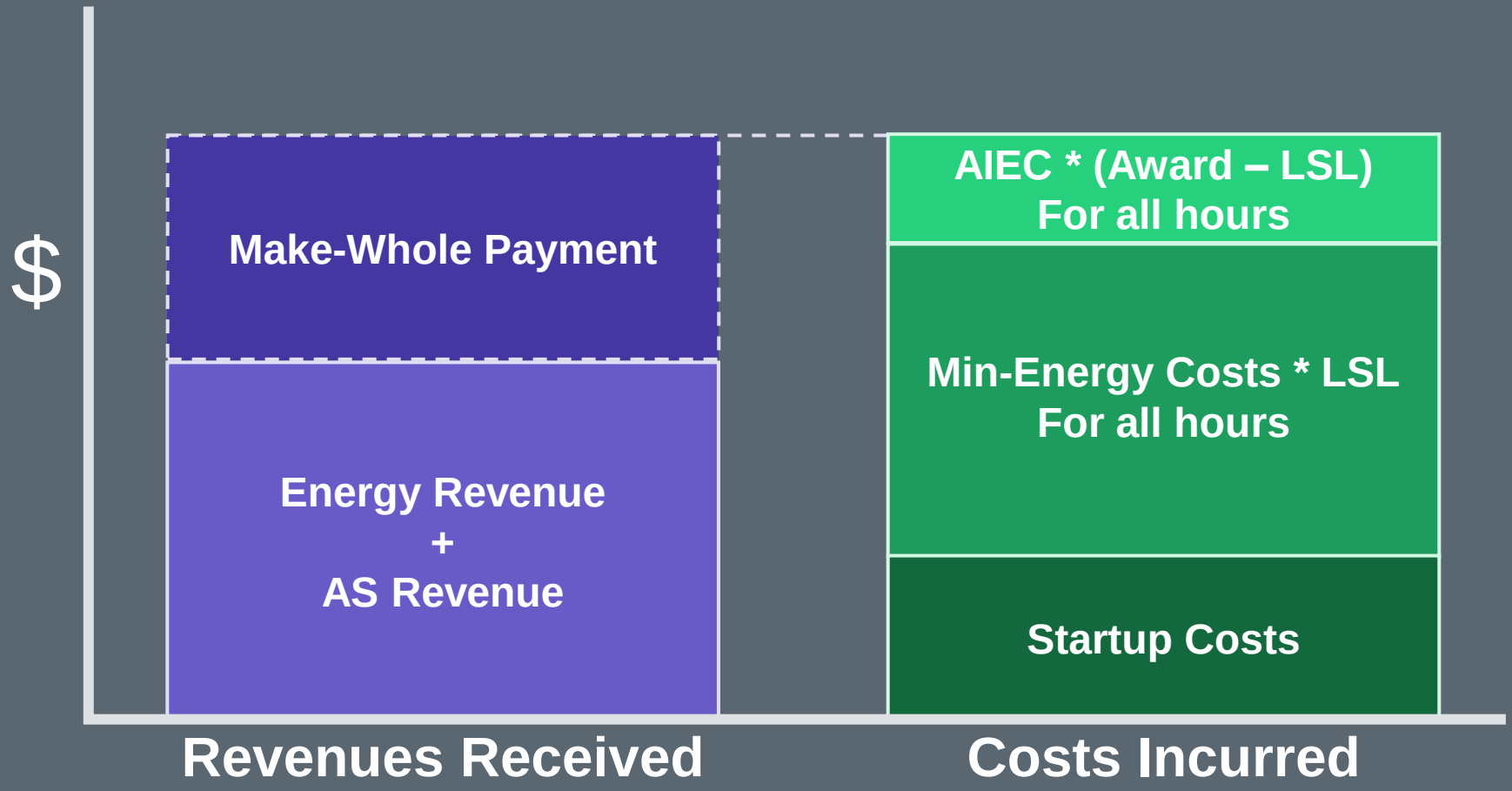
Generation Resource BIGGEN1 is awarded for 4 hours

- Startup Cost: $3000
- Minimum-Energy Cost: $30/MWh @ 50 MW LSL

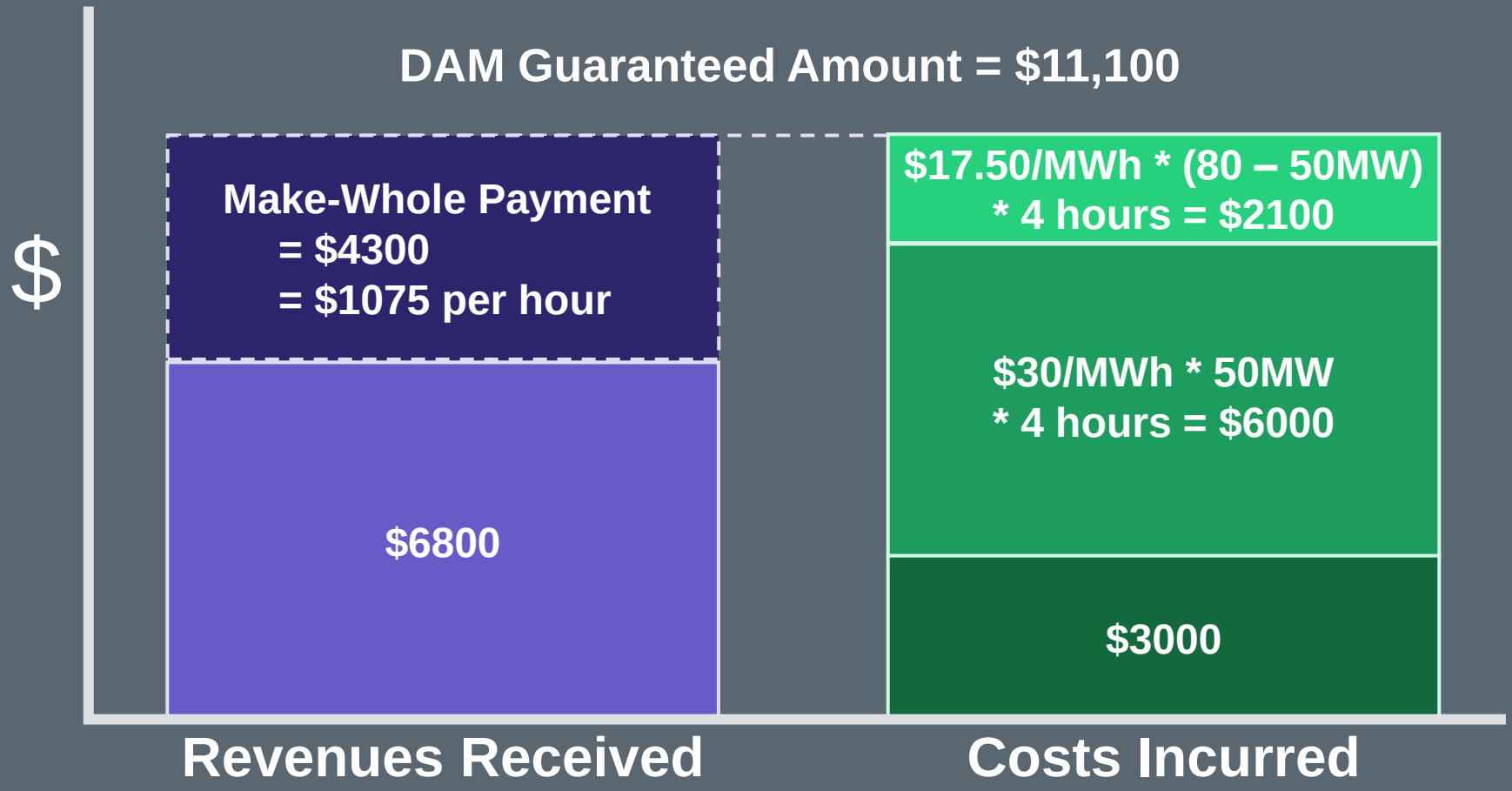
Average Incremental Energy Cost
= Area / (MW above LSL)
= $17.50 / MWh



Example: Day-Ahead Make-Whole Calculation



Example: Day-Ahead Make-Whole Calculation



Generation Resource BIGGEN1 is awarded for 4 hours

- Energy Award: 80MW @ $20
- ECRS Award: 10MW @ $10

	Energy Revenue	AS Revenue	Make-Whole Revenue	Total
Hour 1	$1600	$100	$1075	$2775
Hour 2	$1600	$100	$1075	$2775
Hour 3	$1600	$100	$1075	$2775
Hour 4	$1600	$100	$1075	$2775
Total	$6400	$400	$4300	$11,100

1. Day-Ahead Market Resource Settlement
2. Real-Time Resource Settlement
3. Settlement of RUC-Committed Resources

Real-Time Energy Imbalance

$$(-1)\left[\left(\begin{array}{c}\text{DAM Energy Purchases}\\+\\\text{Trade Energy Purchases}\end{array}\right)-\left(\begin{array}{c}\text{DAM Energy Sales}\\+\\\text{Trade Energy Sales}\end{array}\right)\right]*\text{RTSPP}$$

$$+\ (-1)\left[\text{Metered Generation}\right]*\text{RTRMPR}$$

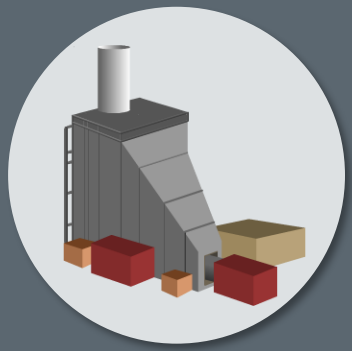
RTSPP = Real-Time Settlement Point Price

Settles Financial Transactions

RTSPP = RTRSVPOR + RTRDP + Time-Weighted Average (LMPs)

RTRSVPOR	Real-Time Reserve Price for On-Line Reserves
RTRDP	Real-Time On-Line Reliability Deployment Price

RTRMPR = Real-Time Resource Meter Price



Settles Physical Energy Production

RTRMRP = RTRSVPOR + RTRDP + (Base-Point * Time)-Weighted Average (LMPs)

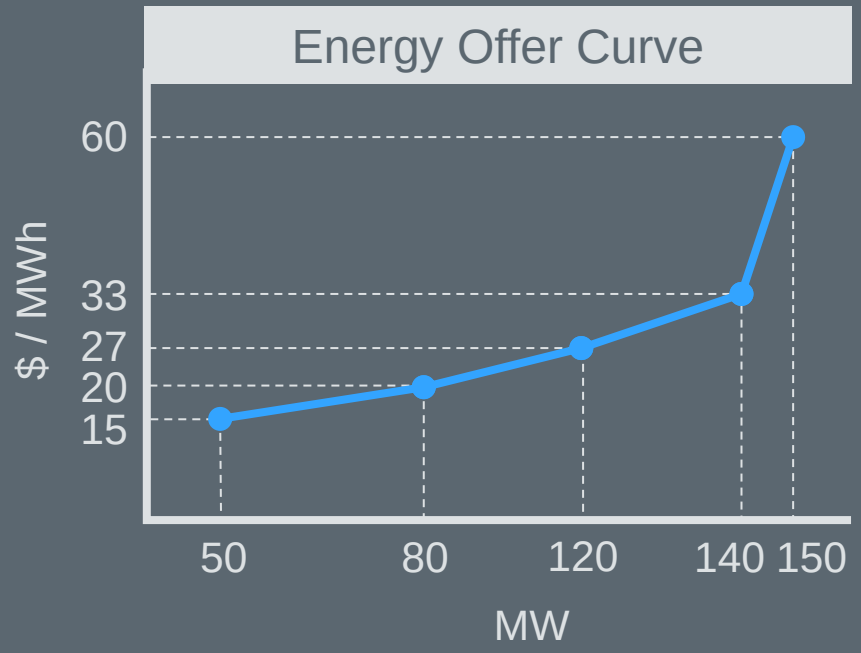
RTRSVPOR	Real-Time Reserve Price for On-Line Reserves
RTRDP	Real-Time On-Line Reliability Deployment Price

Real-Time Energy Settlement
Scenario 1

Generation Resource BIGGEN1 was awarded in DAM and runs in Real-Time

- Awarded 80MW each hour for Hours 1 - 4
- On-line and dispatched in Real-Time during Hours 1 - 4

Hour 1	RTRMPR	RTSPP	MWh
0015	19	18	18
0030	20	20	20
0045	22	21	22
0100	23	22	24
		Total	84



Real-Time Energy Imbalance for Interval 0015:

$$(-1)\left(\left(\begin{array}{c}\text{DAM Energy Purchases}\\+\\\text{Trade Energy Purchases}\end{array}\right)-\left(\begin{array}{c}\text{DAM Energy Sales}\\+\\\text{Trade Energy Sales}\end{array}\right)\right)*\text{RTSPP}$$

$$+\ (-1)\left(\text{Metered Generation}\right)*\text{RTRMPR}$$

Which simplifies and re-arranges to . . .

$$(-1)*\left(\text{Metered Generation}*\text{RTRMPR}-\left(\begin{array}{c}\text{DAM Energy Sales}\\+\\\text{Trade Energy Sales}\end{array}\right)*\text{RTSPP}\right)$$

Real-Time Energy Imbalance for Interval 0015:

$$(-1) * \left[\text{Metered Generation} * \text{RTRMPR} - \left(\begin{array}{c} \text{DAM Energy Sales} \\ + \\ \text{Trade Energy Sales} \end{array} \right) * \text{RTSPP} \right]$$

$$(-1) * \left[18\ \text{MWh} * \$19/\text{MWh} - \boxed{?} * \$18/\text{MWh} \right] = \boxed{?}$$

Real-Time Energy Imbalance for Interval 0045:

$$(-1) * \left[\text{Metered Generation} * \text{RTRMPR} - \left(\begin{array}{c} \text{DAM Energy Sales} \\ + \\ \text{Trade Energy Sales} \end{array} \right) * \text{RTSPP} \right]$$

$$(-1) * \left[22\ \text{MWh} * \$22/\text{MWh} - ? * \$21/\text{MWh} \right] = ?$$

Real-Time Revenues across all hours

- On-line and dispatched in Real-Time during Hours 1 – 4
- Assume ECRS was never deployed

Is that all the revenue for BIGGEN1?

	Real-Time Revenue
Hour 1	$158
Hour 2	$200
Hour 3	$225
Hour 4	$250
Total	$833

BIGGEN1 was also awarded Energy and Responsive Reserve in DAM

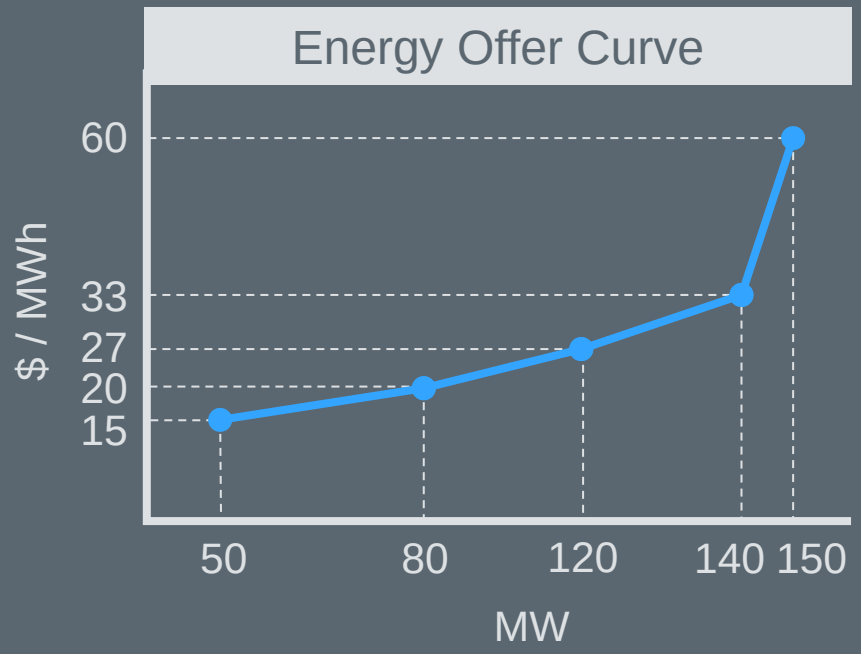
- Energy Award: 80MW @ $20 for Hours 1 - 4
- ECRS Award: 10MW @ $10 for Hours 1 - 4
- Make-Whole payment of $1075 per hour

	Real-Time Revenue	DAM Revenue	Total
Hour 1	$158	$2775	$2993
Hour 2	$200	$2775	$2975
Hour 3	$225	$2775	$3000
Hour 4	$250	$2775	$3025
Total	$833	$11,100	$11,993

Real-Time Energy Settlement
Scenario 2

QSE schedules trades on BIGGEN1 and runs in Real-Time

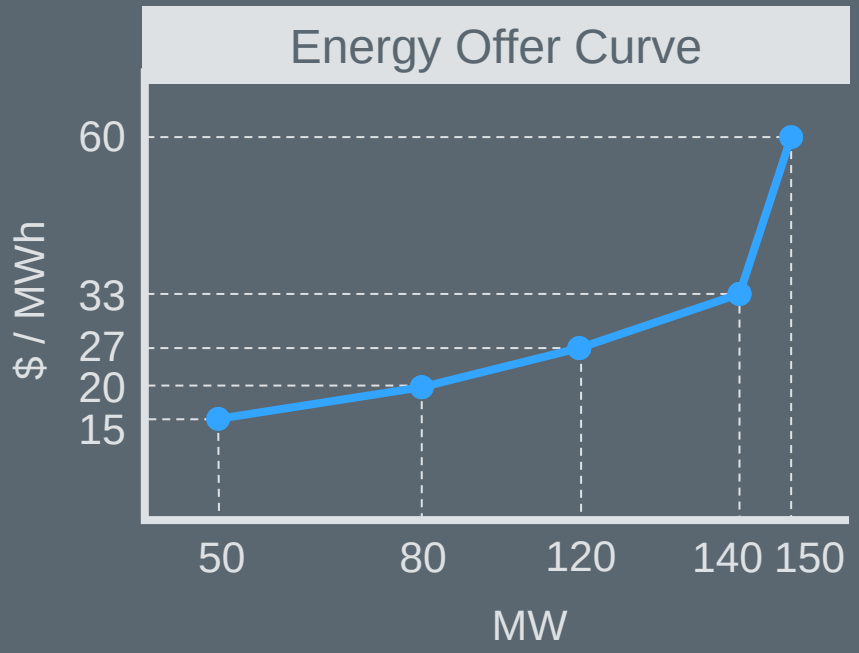
- Startup Cost: $3000
- Minimum-Energy Cost: $30/MWh,
- LSL = 50 MW



QSE schedules trades on BIGGEN1 and runs in Real-Time

- 100MW in trades at BIGGEN Resource Node for Hours 15-18
- QSE starts BIGGEN1 for Hour 15 and runs through Hour 18

Hour 15	RTRMPR	RTSPP	MWh
1415	27	27	30
1430	29	28	31
1445	31	30	33
1500	34	33	35
		Total	129



Real-Time Energy Imbalance for Interval 1415:

$$(-1) * \left[\text{Metered Generation} * \text{RTRMPR} - \left(\begin{array}{c} \text{DAM Energy Sales} \\ + \\ \text{Trade Energy Sales} \end{array} \right) * \text{RTSPP} \right]$$

$$(-1) * \left[30\ \text{MWh} * \$27/\text{MWh} - ? * \$27/\text{MWh} \right] = ?$$

Real-Time Revenues across all hours

- 100MW in trades at BIGGEN Resource Node for Hours 15-18
- QSE starts BIGGEN1 for Hour 15 and runs through Hour 18

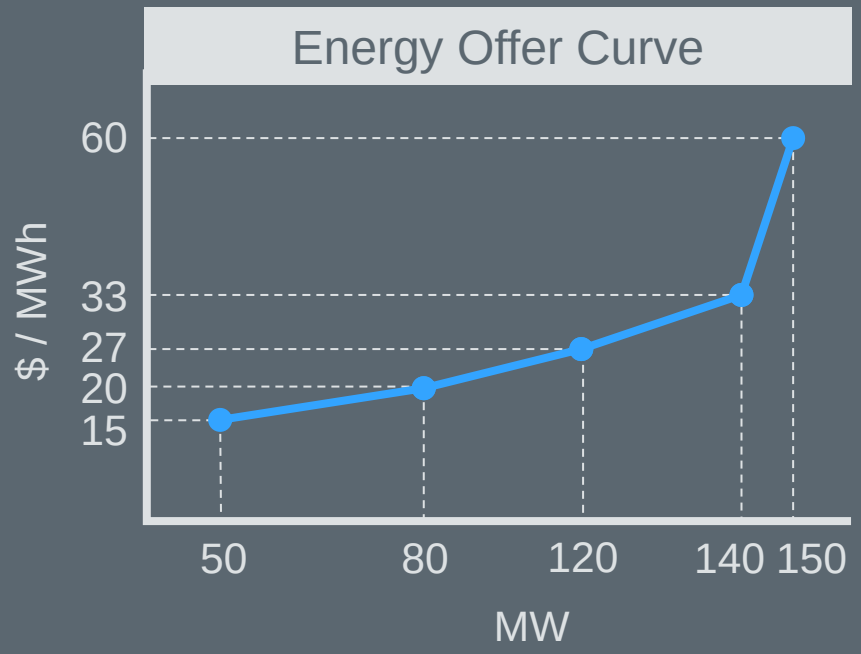
Is this Real-Time Revenue sufficient for BIGGEN1?

	Real-Time Revenue
Hour 14	$300
Hour 15	$972
Hour 16	$1122
Hour 17	$1275
Hour 18	$802
Hour 19	$406
Total	$ 4877

1. Day-Ahead Market Resource Settlement
2. Real-Time Resource Settlement
3. Settlement of RUC-Committed Resources

Generation Resource BIGGEN1 is committed by RUC

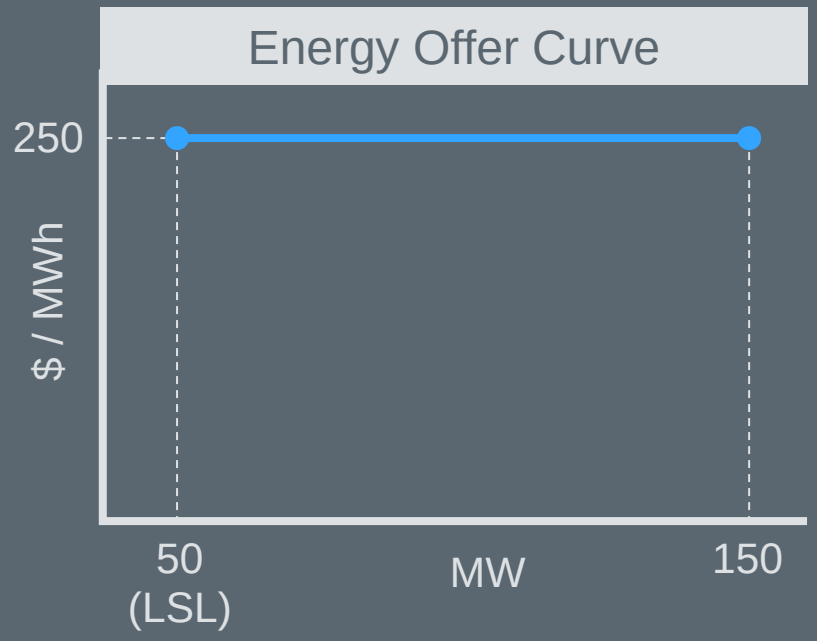
- Startup Cost: $3000
- Minimum-Energy Cost: $30/MWh
- LSL = 50 MW



Generation Resource BIGGEN1 is committed by RUC

- Committed for Hours 7-10
- QSE starts Resource and ramps to LSL by 0600

Hour 7	RTRMPR	RTSPP	MWh
0615	20	20	12.5
0630	20	20	12.5
0645	20	20	12.5
0700	20	20	12.5
		Total	50



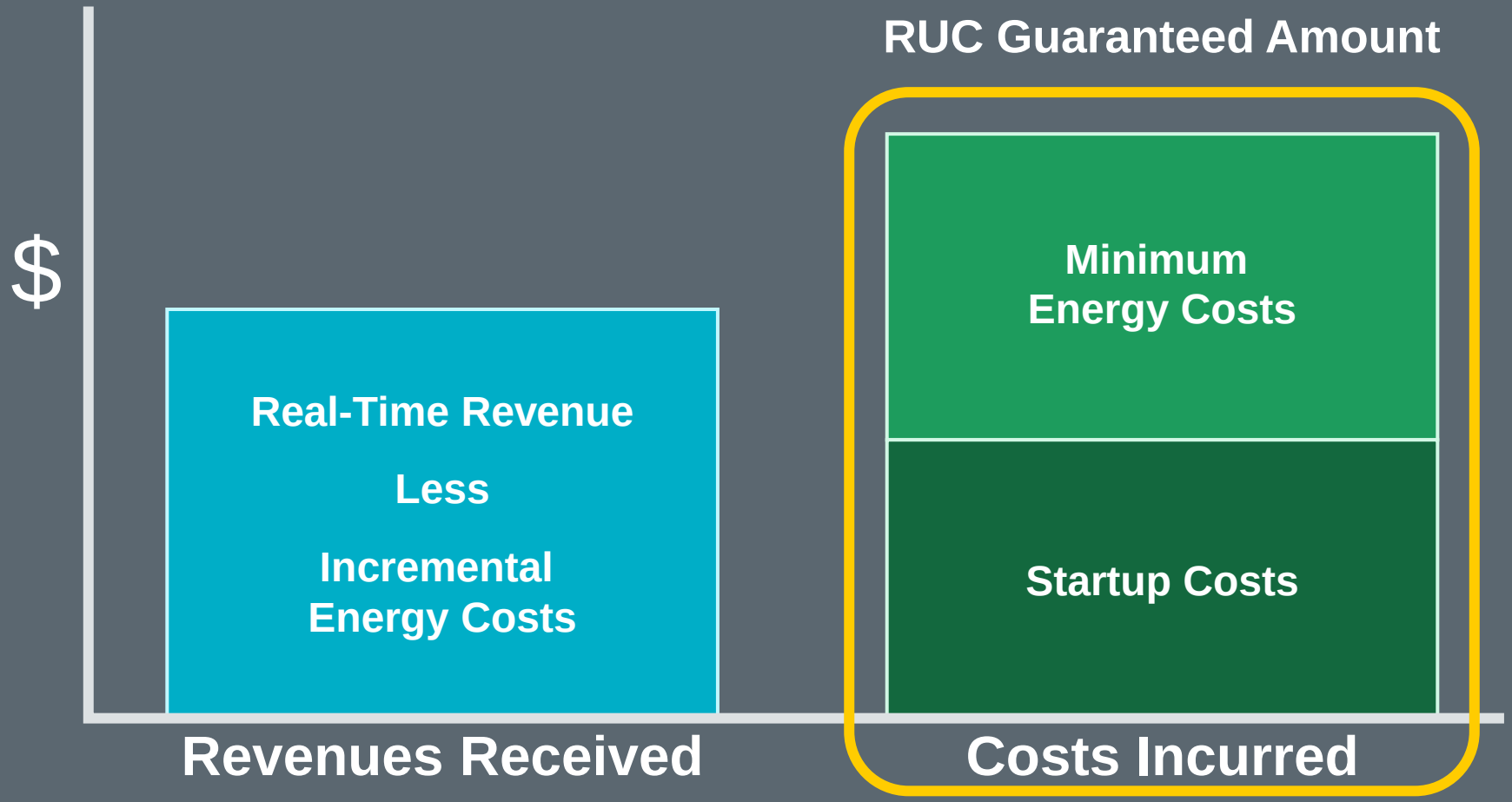
Real-Time Energy Imbalance for Interval 0615:

$$(-1) * \left[\text{Metered Generation} * \text{RTRMPR} - \left(\begin{array}{c} \text{DAM Energy Sales} \\ + \\ \text{Trade Energy Sales} \end{array} \right) * \text{RTSPP} \right]$$

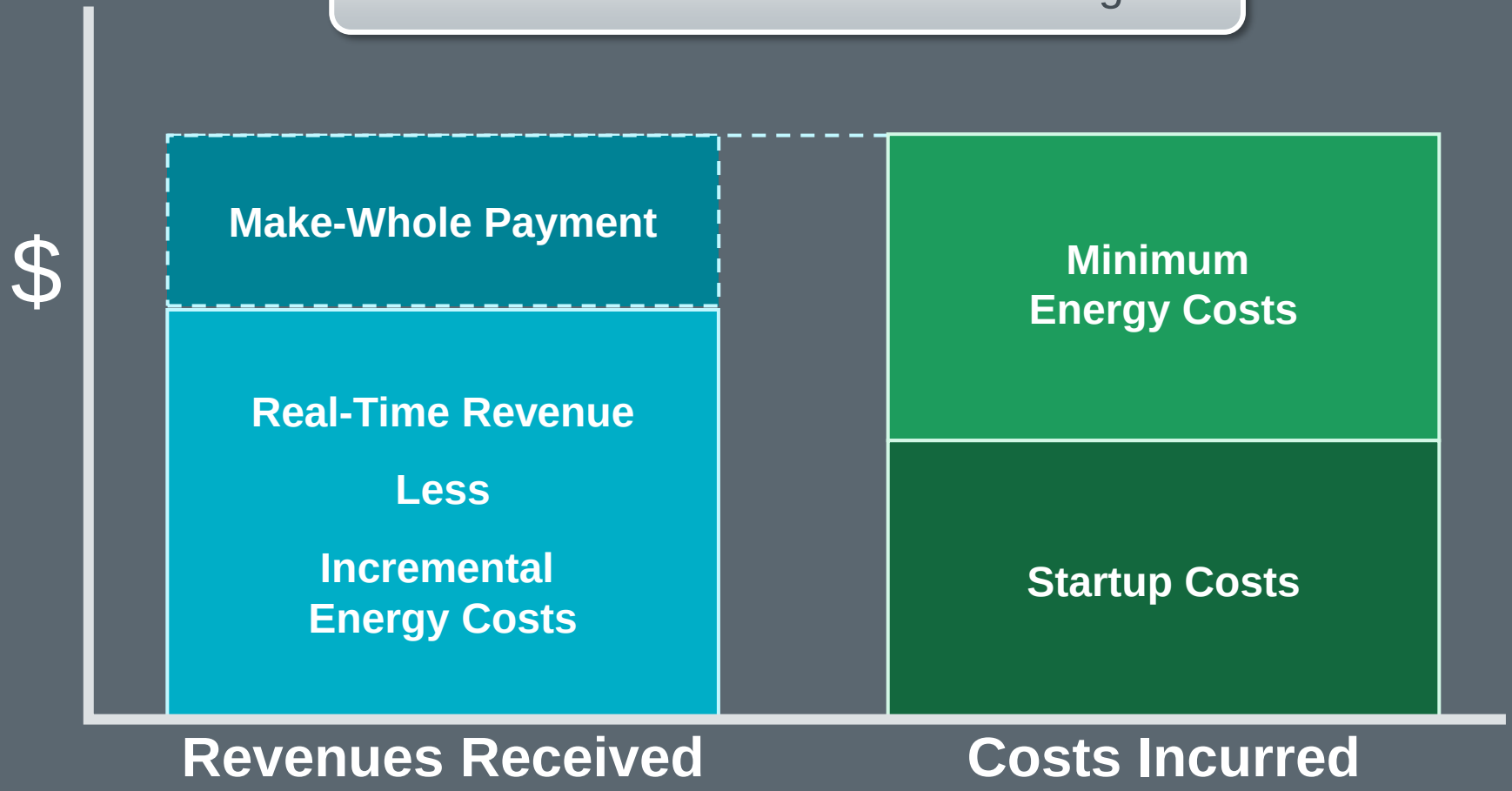
$$(-1) * \left[12.5\ \text{MWh} * \$20/\text{MWh} - \boxed{?} \right] = \boxed{?}$$

At this rate, will they recover their Startup and Minimum-Energy Costs?

RUC Make-Whole Payment



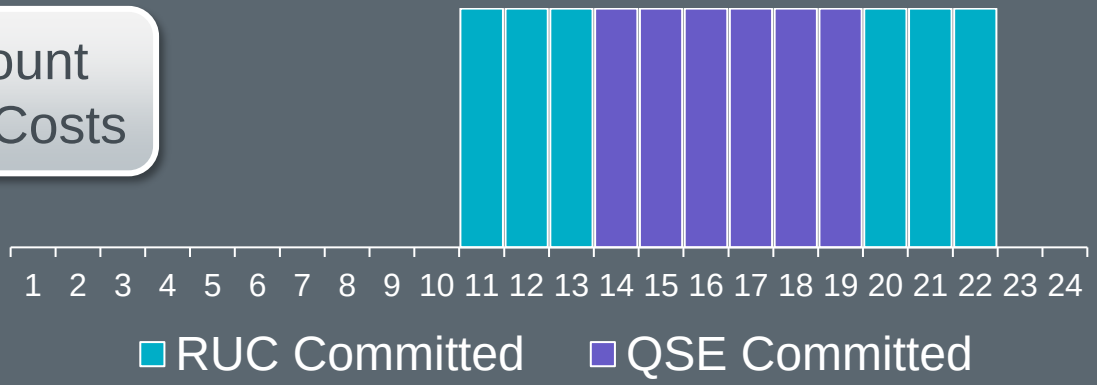
Resource must incur costs to be eligible



One Start per contiguous block of committed hours

- QSE initially commits
- RUC extends commitment

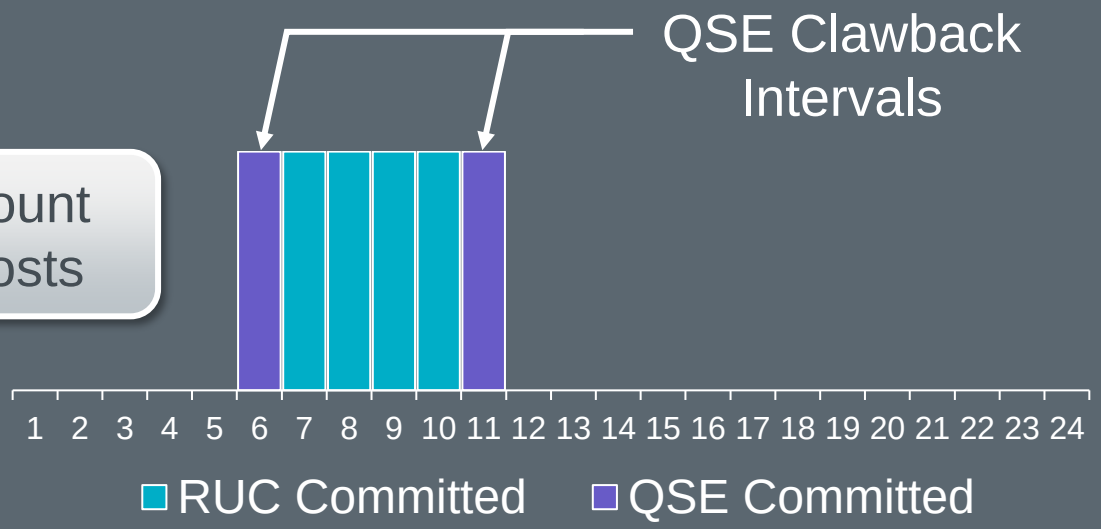
RUC Guaranteed Amount will not include Startup Costs



One Start per contiguous block of committed hours

- RUC initially commits
- QSE extends commitment

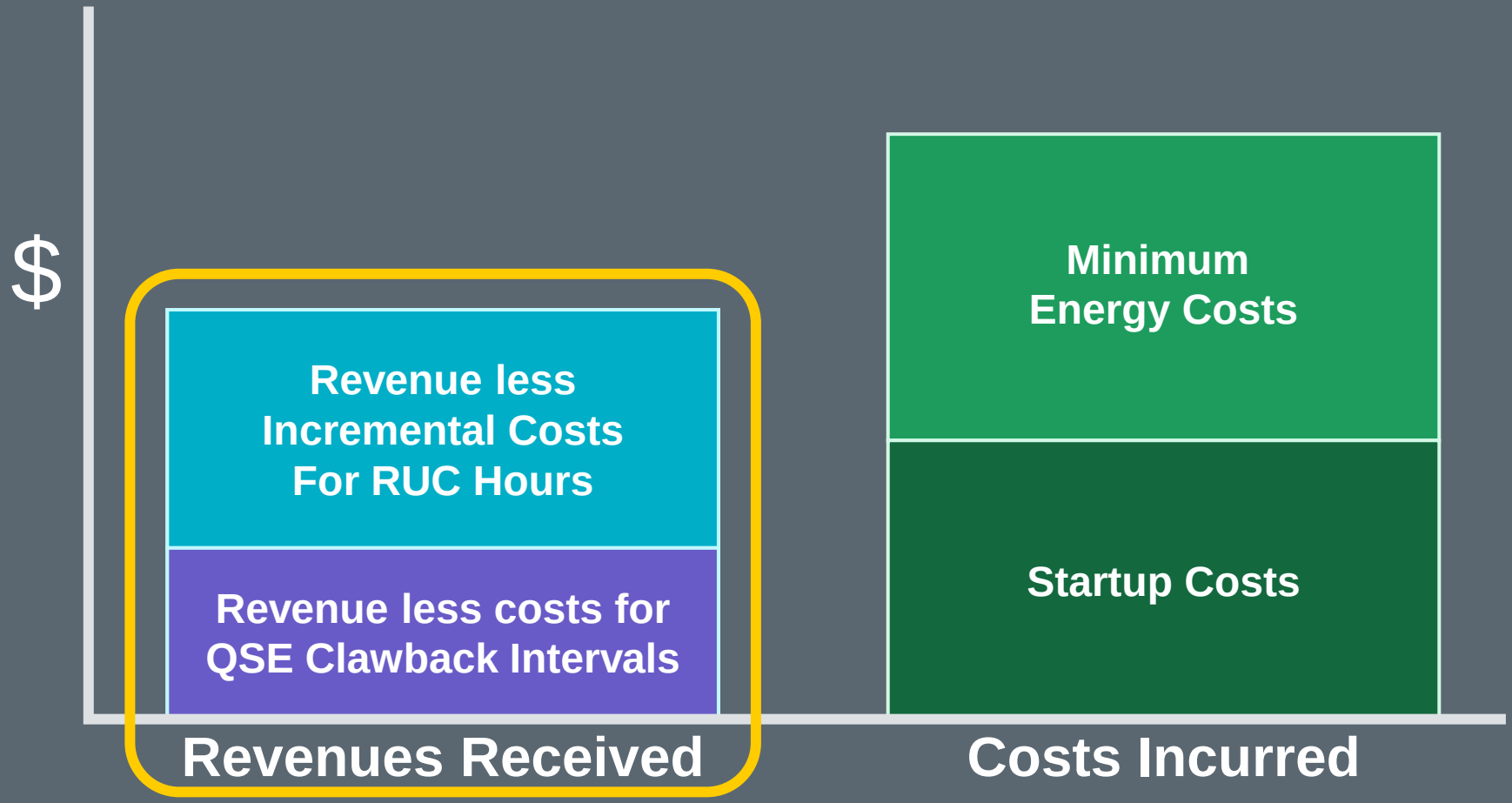
RUC Guaranteed Amount will include Startup Costs



Make-Whole costs are capped

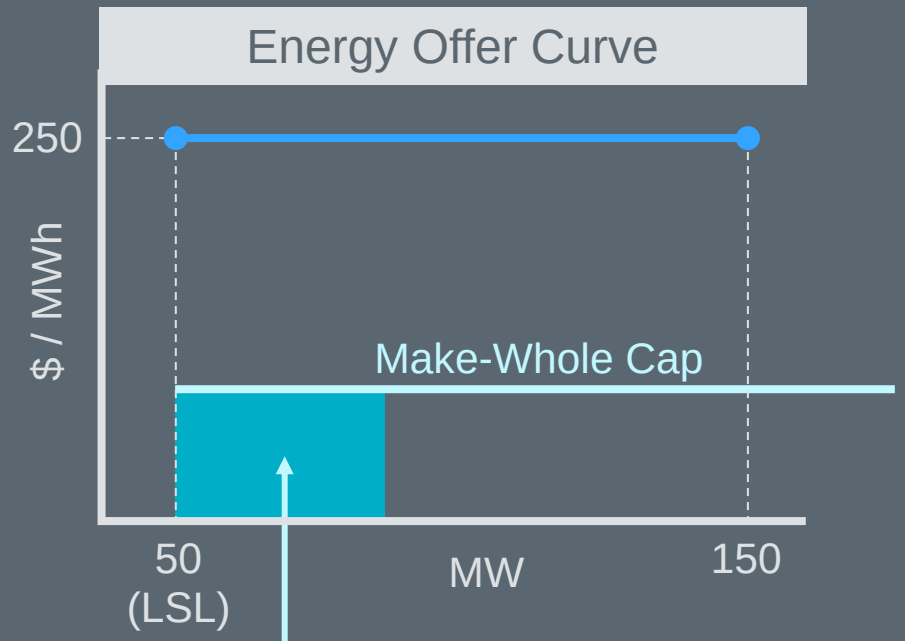
- Approved Verifiable Costs, if available
- Otherwise, Generic Costs from Protocols

Real-Time Revenue divided into two types



Revenue less Incremental Costs for RUC Hours

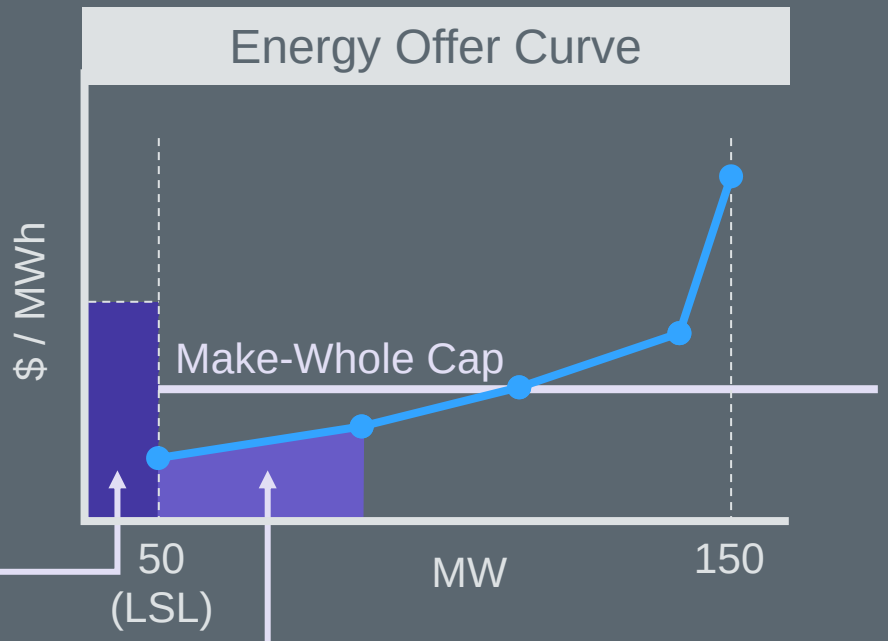
- Incremental Costs from Energy Offer Curve
- Subject to Cap



Average Incremental Energy Cost = Area / (MW Output above LSL)

Revenue less costs for QSE Clawback Intervals

- Incremental Costs from Energy Offer Curve
- Subject to Cap



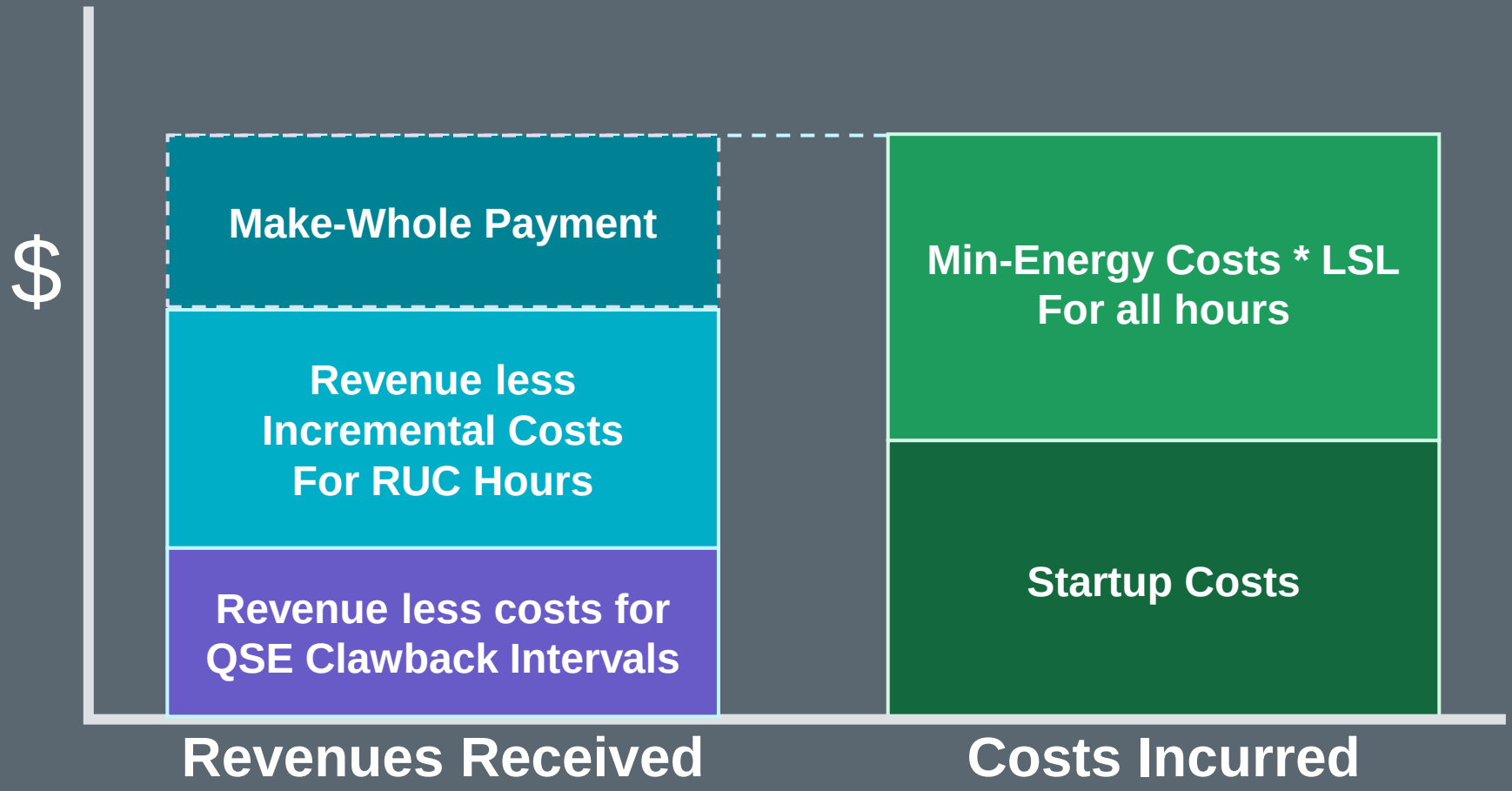
Minimum-Energy Cost

Average Incremental Energy Cost
= Area / (MW Output above LSL)

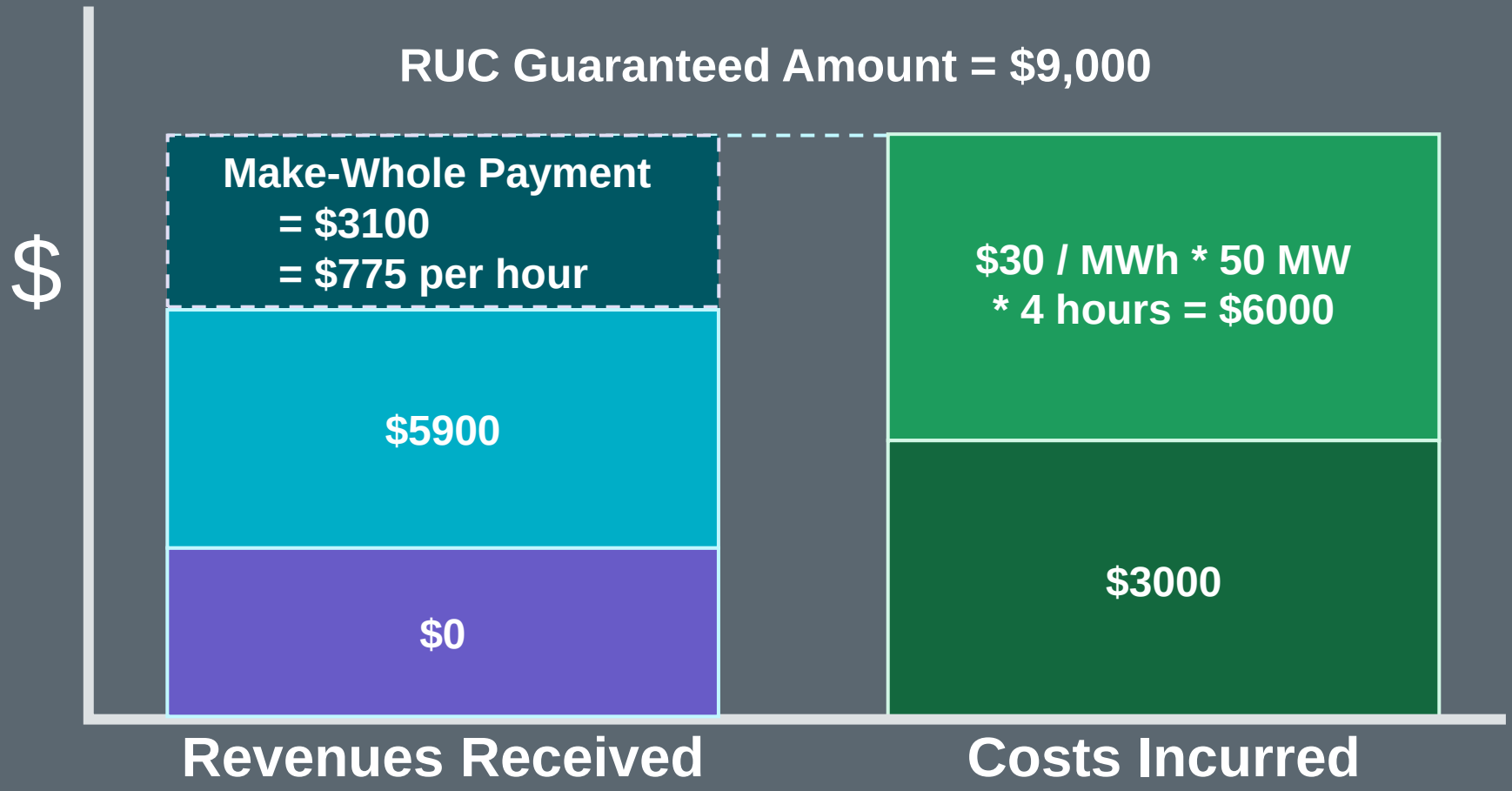
BIGGEN1 starts in Hour 6 and shuts down in Hour 11

	Revenue less Incremental Costs for RUC Hours	Revenue less Costs for QSE Clawback Intervals
Hour 6		$0
Hour 7	$1000	
Hour 8	$1900	
Hour 9	$2000	
Hour 10	$1000	
Hour 11		$0
Total	$5900	$0

Example: RUC Make-Whole Calculation



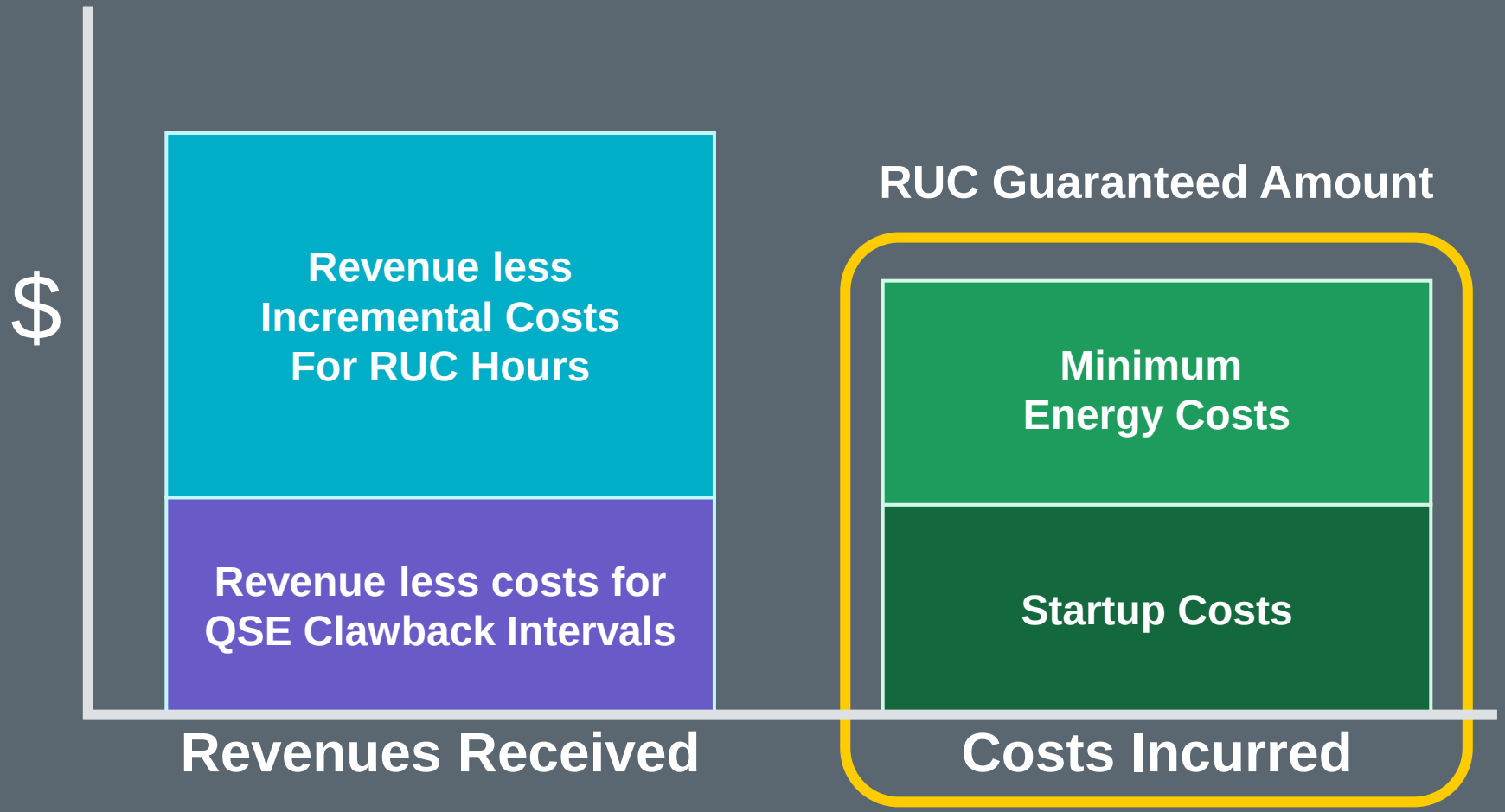
Example: RUC Make-Whole Calculation



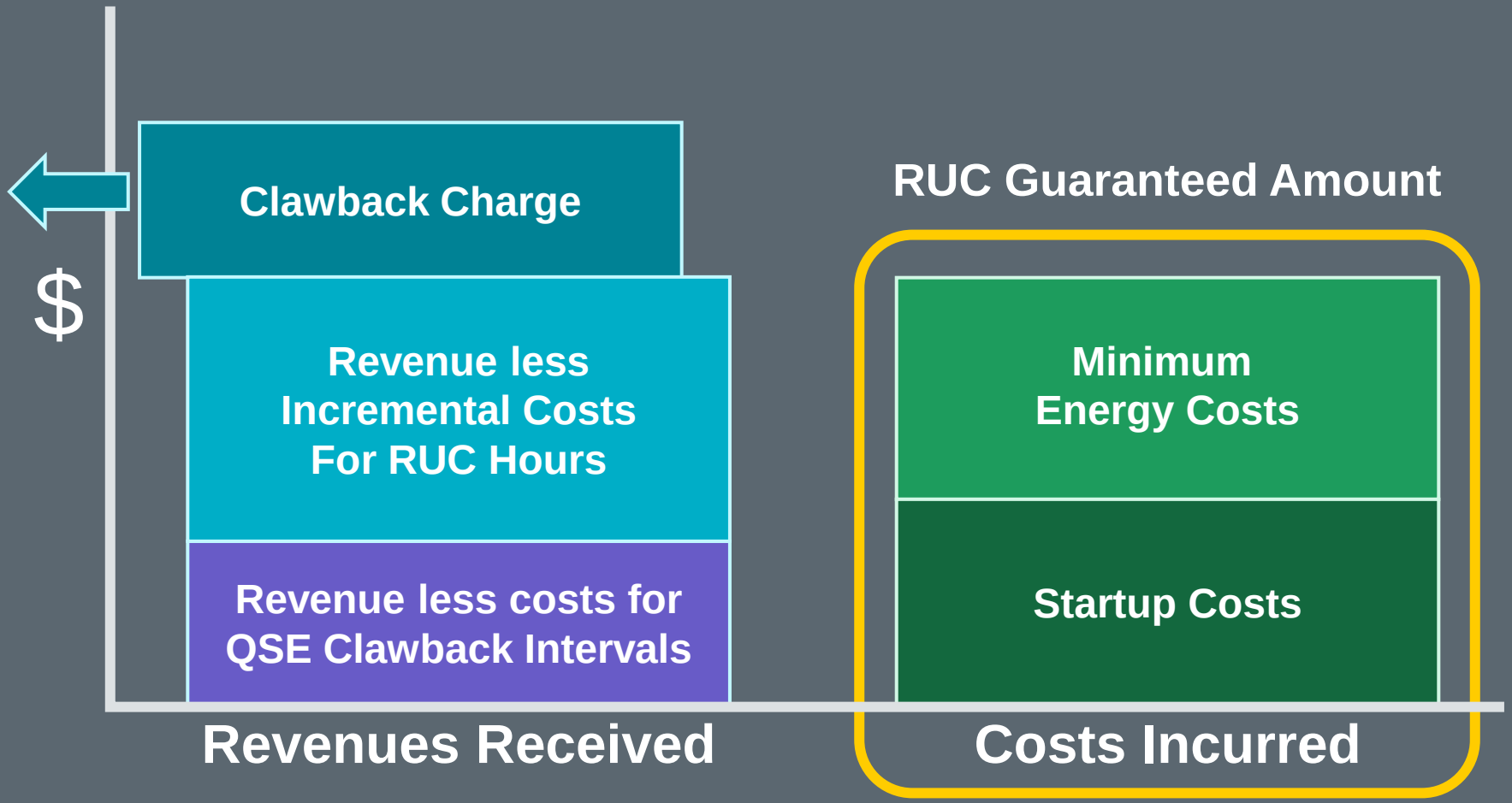
Generation Resource BIGGEN1 is committed by RUC

	Real-Time Revenue	Make-Whole Revenue	Total
Hour 6	$500	N/A	$500
Hour 7	$1000	$775	$1775
Hour 8	$2800	$775	$3575
Hour 9	$3020	$775	$3795
Hour 10	$1000	$775	$1775
Hour 11	$500	N/A	$500
Total	$8820	$3100	$11,920

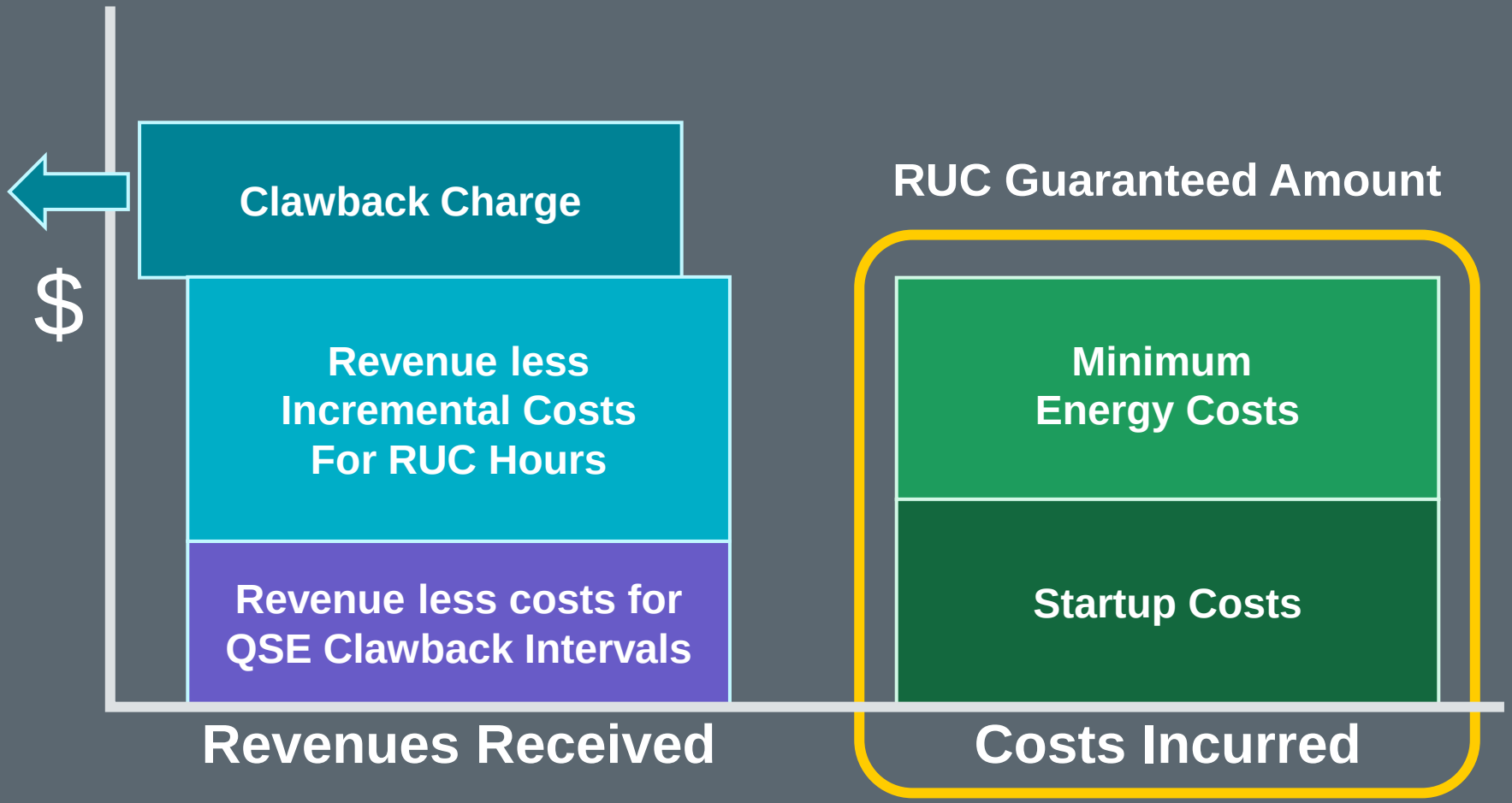
What if revenues are greater than costs?



What if revenues are greater than costs?



Any way to avoid RUC Clawback Charges?



Course Wrap-Up

Suite of Resource Courses

Format	Title
WBT	Resources in ERCOT
	Resource Responsibilities in ERCOT

Format	Title	Topic
ILT	Resources and Day-Ahead Operations	Resource Constraints in the Day-Ahead Market
		Resource Commitment in the Day-Ahead Market
		Resource Commitment after the Day-Ahead Market
	Resources and Real-Time Operations	Resource Dispatch in Real-Time
		Resource Reserve Deployment in Real-Time
		Resources and their Financial Impacts

ERCOT Client Services
Clientservices@ercot.com

ERCOT Mailing Lists
http://lists.ercot.com/

ERCOT Nodal Market Protocols
http://www.ercot.com/mktrules/nprotocols/

ERCOT Training
http://www.ercot.com/services/training/

Market Education Contact
Training@ercot.com

Scan this QR code to take the course survey!

https://www.surveymonkey.com/r/ERCOTILT