



Economic Dispatch and Border Adjustment Options

CPSTF

August 26, 2019

- **Today:** Review basics of economic dispatch and the three border adjustment options
 - 1) No Border Adjustment
 - 2) One-way Border Adjustment
 - 3) Two-way Border Adjustment

- **Disclaimer:**

- PJM **does not** endorse any of the three options and is solely providing this information to support stakeholder discussions
- The examples used are **solely** intended to help illustrate the concepts presented and are not intended to be a representation of actual system conditions

Economic Dispatch

Three components of a resource's offer:

Start-up cost
(\$/start)

Incremental
energy cost
(\$/MWh)

No-load cost
(\$/hour)

- **Unit Commitment** — Determines which units to turn on (committing) and when based on forecasted load and other requirements. Unit commitment is then fixed going into economic dispatch.
- **Economic Dispatch** — Determines megawatt output for each resource that is online
- **Locational Prices** — Determined by solving the economic dispatch



- **Holds the commitment from the unit commitment fixed**
- Determines the least expensive way to supply load in the system
- Determines the output of all online units to keep the system in balance

Prices are determined by solving the economic dispatch.

- Similar to unit commitment formulation
- The difference:
 - No integer variables, as the unit commitment is held fixed
- **Start-up** and **no-load** costs are not considered, as they become constants

Objective Function – Total Production Cost

Minimize for all resources:

$$\text{Incremental Energy Cost} + \text{Start-up Cost} + \text{No-Load Cost}$$

System Balance

$$\text{Total Generation} - \text{Total Load} - \text{Losses} = 0$$

Integer variables are now fixed, so they do not affect the solution.

Transmission Constraints

The flow on each line must be below its operating limit.

Resource Capacity Constraints

The output of each resource must be within its operating range.

Unit Commitment Constraints

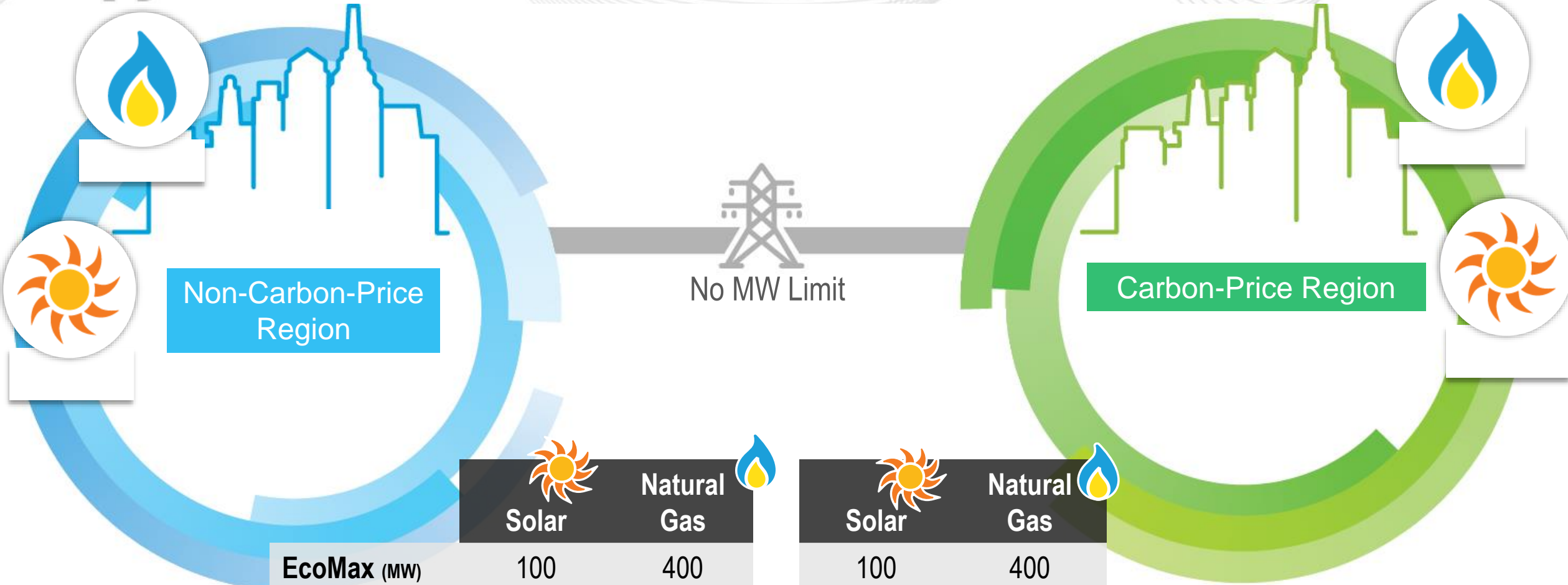
Each Resource is **On (1)**.

Economic dispatch only dispatches resources that are already online.

Border Adjustment Options

- The border adjustment options can be for any border between two regions where one region has a carbon price and the other does not
- The options will be presented using simple examples to help illustrate the concepts

- There is **no** perfect way to deal with flows between regions with and without a carbon price. Each border adjustment option has its **advantages** and **disadvantages**, which will be highlighted.
- Power produced by one generator is **indistinguishable** from power produced by another. However, dispatch decisions can be tracked precisely and associated with serving load in one region or another. This concept will be illustrated in the examples.



	Solar	Natural Gas	Solar	Natural Gas
EcoMax (MW)	100	400	100	400
Offer (\$/MWh)	0	30	0	20
Offer with Carbon (\$/MWh)	0	120	0	100

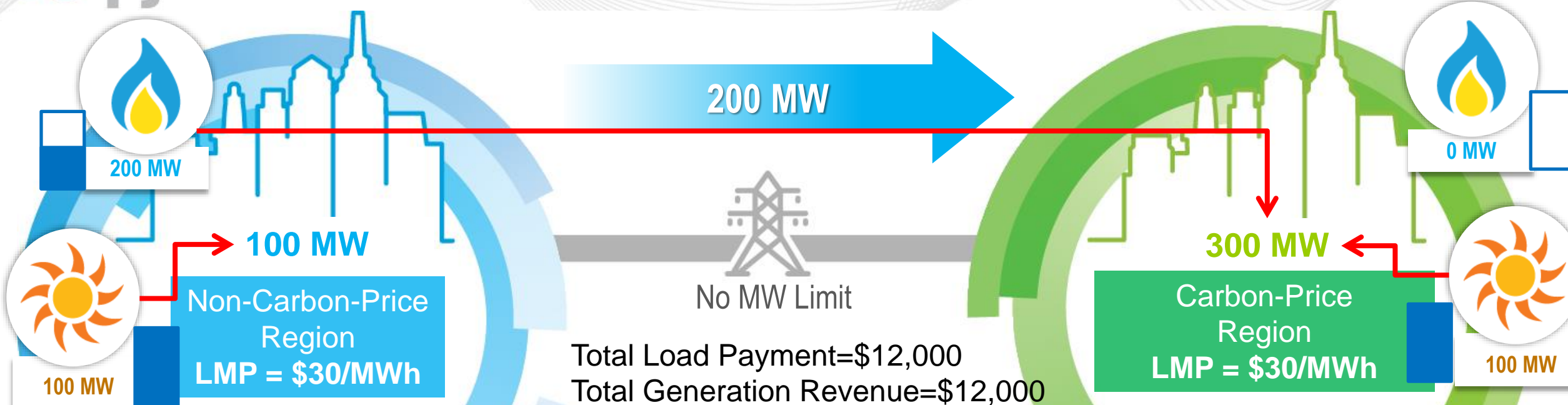
- Note:
 - Assume the natural gas generator in the carbon-price region is located in State A
 - The natural gas generator in the carbon-price region has an **obligation** to pay State A for its carbon emissions at a rate of 80 \$/MWh
 - This financial transaction takes place outside of the market and the grid operator's settlement process

Option 1: No Border Adjustment (Status Quo)

- Generators located in the **carbon-price region**
 - Dispatched using offers that **include** the cost of carbon
- Generators located in the **non-carbon-price region**
 - Dispatched using offers that **do not include** the cost of carbon

Example 1: Net Import to Carbon-Price Region

Example 1: Net Import – No Border Adjustment

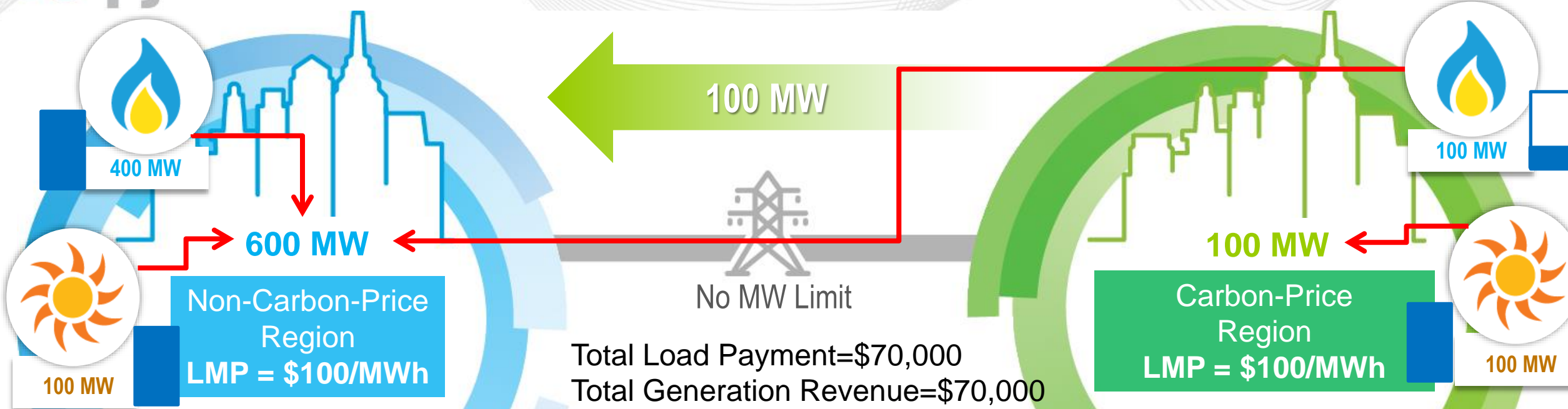


	Solar	Natural Gas	Solar	Natural Gas
EcoMax (MW)	100	400	100	400
Offer (\$/MWh)	0	30	0	20
Offer with Carbon (\$/MWh)	0	120	0	100

- Revenue Adequate:
 - Total Load Payments = Total Generator Revenue
- In the carbon-price region, the natural gas generator is not dispatched
 - No carbon revenue collected by State A

Example 2: Net Export from Carbon-Price Region

Example 2: Net Export – No Border Adjustment



	Solar	Natural Gas	Solar	Natural Gas
EcoMax (MW)	100	400	100	400
Offer (\$/MWh)	0	30	0	20
Offer with Carbon (\$/MWh)	0	120	0	100

- Revenue Adequate:
 - Total Load Payments = Total Generator Revenue
- In the carbon-price region, the natural gas generator is dispatched using an offer that includes the cost of carbon
 - Carbon revenue collected by State A:
 $(100\$/MWh - 20\$/MWh) * 100MW * 1h = \$8,000$

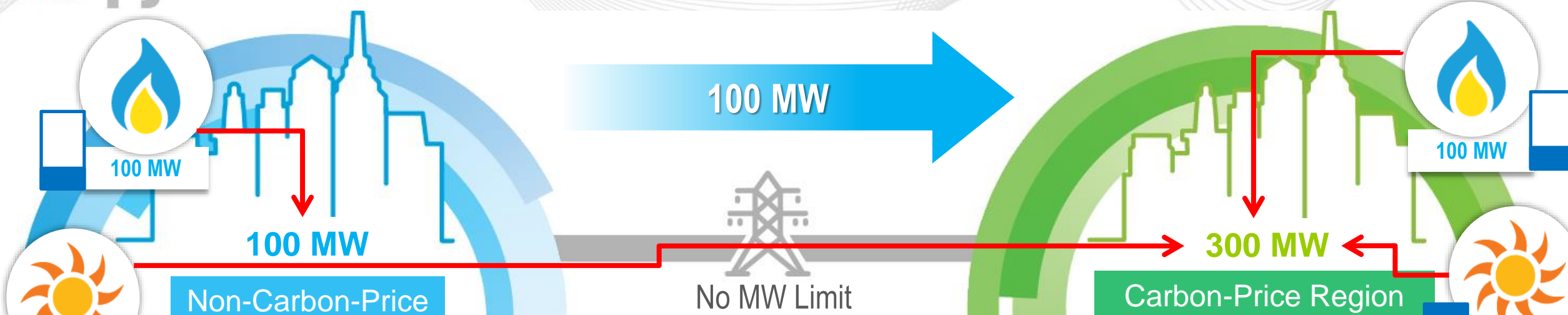
- Advantages:
 - Revenue Adequate
(Total Load Payments = Total Generator Revenue)
- Disadvantages:
 - Carbon-emitting generation inside the carbon-price region is dispatched at a disadvantage to carbon-emitting generation outside the carbon-price region
 - In the net export case, generator offers that include the cost of carbon can potentially set the LMP in the non-carbon-price region

Option 2: One-Way Border Adjustment

- Generators located in the **carbon-price region**
 - Dispatched using offers that **include** the cost of carbon
- Generators located in the **non-carbon-price region**
 - When associated with serving load in the **non-carbon-price region**
 - Dispatched using offers that **do not include** the cost of carbon
 - When associated with serving load in the **carbon-price region**
 - Dispatched using offers that **include** the cost of carbon
- The **carbon component of the LMP** is the marginal cost of carbon compliance

Example 3: Net Import to Carbon-Price Region

Example 3: Net Import – One-Way Border Adjustment



Non-Carbon-Price Region
LMP = \$30/MWh

Carbon-Price Region
LMP = \$100/MWh
LMP_{carbon} = \$70/MWh

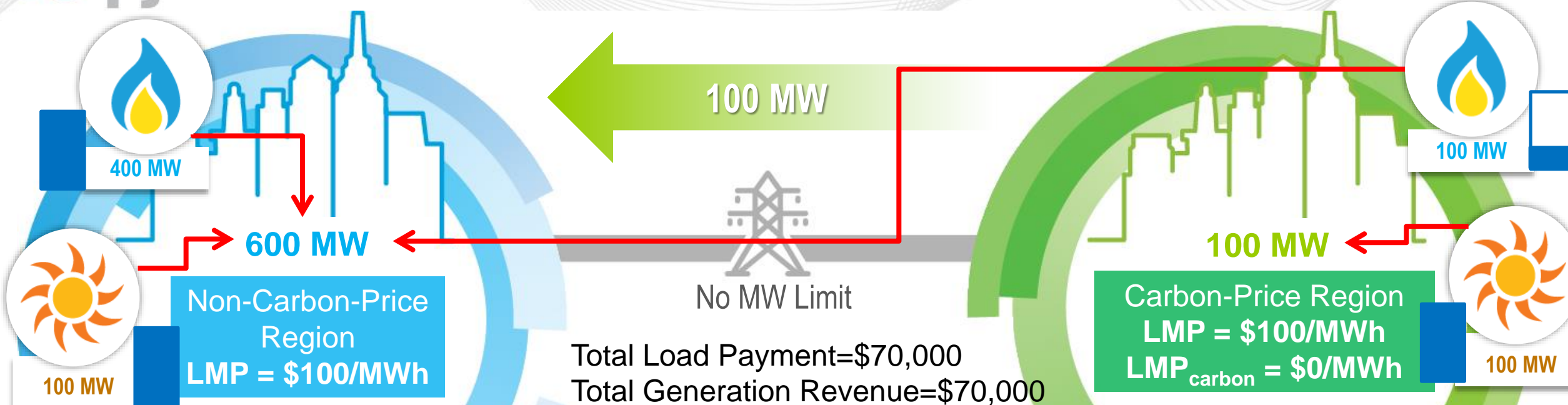
Total Load Payment = \$33,000
Total Generation Revenue = \$26,000
Total Surplus = \$7,000

	Solar	Natural Gas	Solar	Natural Gas
EcoMax (MW)	100	400	100	400
Offer (\$/MWh)	0	30	0	20
Offer with Carbon (\$/MWh)	0	120	0	100

- Revenue Adequate:
 - Total Load Payments > Total Generator Revenue
 - Surplus \$7,000 is allocated back to the carbon-price-region
- In the carbon-price-region, the natural gas generator is dispatched using an offer that includes the cost of carbon
 - Carbon revenue collected by State A:
 $(100\$/MWh - 20\$/MWh) * 100MW * 1h = \$8,000$

Example 4: Net Export from Carbon-Price Region

Example 4: Net Export – One-Way Border Adjustment



	Solar	Natural Gas	Solar	Natural Gas
EcoMax (MW)	100	400	100	400
Offer (\$/MWh)	0	30	0	20
Offer with Carbon (\$/MWh)	0	120	0	100

- Revenue Adequate:
 - Total Load Payments = Total Generator Revenue
- In the carbon-price-region, the natural gas generator is dispatched using an offer that includes the cost of carbon
 - Carbon revenue collected by State A:
 $(100\$/MWh - 20\$/MWh) * 100MW * 1h = \$8,000$

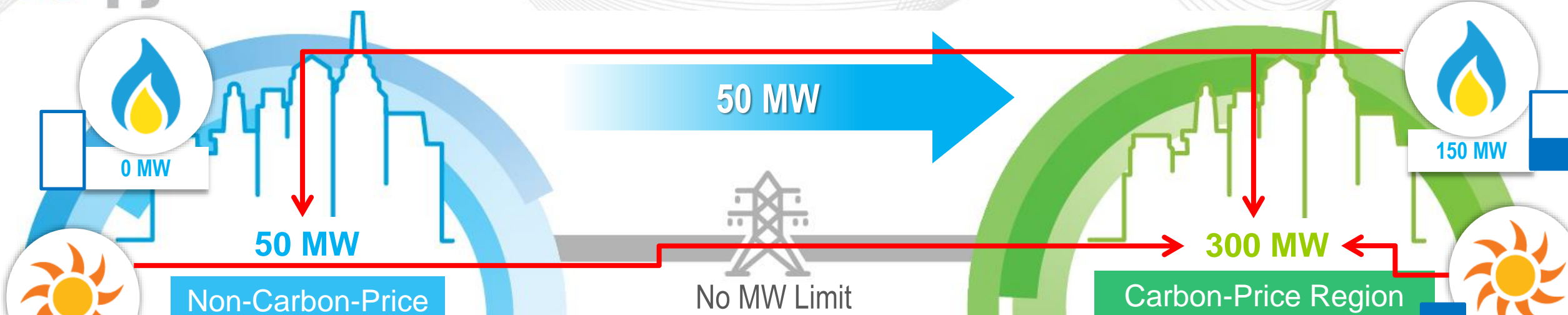
- Advantages:
 - Revenue Adequate – may result in a surplus if there is a non-zero marginal cost of carbon compliance
(Total Load Payments \geq Total Generator Revenue)
 - When serving load in the **carbon-price region**:
 - Carbon-emitting generation inside the carbon-price region is dispatched on a level playing field to carbon-emitting generation outside the carbon-price region
- Disadvantages:
 - In the net export case, generator offers that include the cost of carbon can potentially set the LMP in the non-carbon-price region
 - When serving load in the **non-carbon-price region**:
 - Carbon-emitting generation inside the carbon-price region is dispatched at a disadvantage to carbon-emitting generation outside the carbon-price region

Option 3: Two-Way Border Adjustment

- For all generators:
 - When associated with serving load in the **non-carbon-price region**
 - Dispatched using offers that **do not include** the cost of carbon
 - When associated with service load in the **carbon-price region**
 - Dispatched using offers that **include** the cost of carbon
- The **carbon component of the LMP** is the marginal cost of carbon compliance

Example 5: Net Import to Carbon-Price Region

Example 5: Net Import – Two-Way Border Adjustment



Non-Carbon-Price Region
LMP = \$20/MWh

Carbon-Price Region
LMP = \$100/MWh
LMP_{carbon} = \$80/MWh

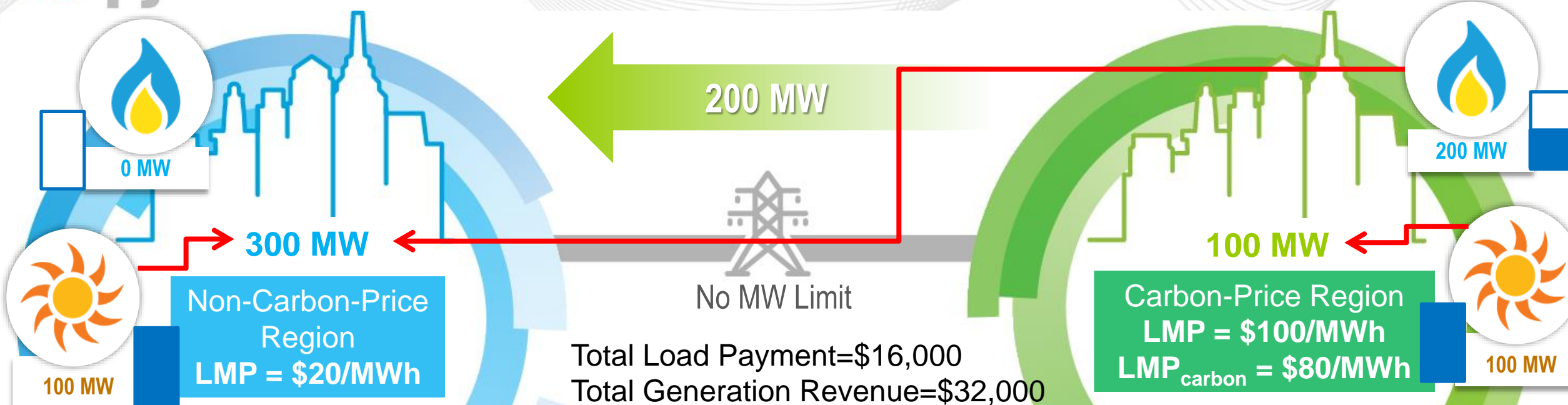
Total Load Payment=\$31,000
Total Generation Revenue=\$27,000
Total Surplus =\$4,000

	Solar	Natural Gas	Solar	Natural Gas
EcoMax (MW)	100	400	100	400
Offer (\$/MWh)	0	30	0	20
Offer with Carbon (\$/MWh)	0	120	0	100

- Revenue Adequate:
 - Total Load Payments > Total Generator Revenue
 - Surplus \$4,000 is allocated back to the carbon-price-region
- In the carbon-price-region, the natural gas generator is dispatched using an offer that includes the cost of carbon
 - Carbon revenue collected by State A:
 $(100\$/MWh - 20\$/MWh) * 150MW * 1h = \$12,000$

Example 6: Net Export from Carbon-Price Region

Example 6: Net Export – Two-Way Border Adjustment



Total Load Payment=\$16,000
 Total Generation Revenue=\$32,000
Total Deficit=\$16,000

	Solar	Natural Gas	Solar	Natural Gas
EcoMax (MW)	100	400	100	400
Offer (\$/MWh)	0	30	0	20
Offer with Carbon (\$/MWh)	0	120	0	100

- Not Revenue Adequate:
 - Total Load Payments < Total Generator Revenue
 - Deficit \$16,000 is allocated back to the carbon-price-region
- In the carbon-price-region, the natural gas generator is dispatched using an offer that includes the cost of carbon
 - Carbon revenue collected by State A:
 $(100\$/MWh - 20\$/MWh) * 200MW * 1h = \$16,000$

- Advantages:
 - Carbon-emitting generation inside the carbon-price region is dispatched on a level playing field to carbon-emitting generation outside the carbon-price region
- Disadvantages:
 - For the net export case, it may not be revenue adequate (i.e. Total Load Payments \leq Total Generator Revenues)