Economic Dispatch and Border Adjustment Options

CPSTF

August 26, 2019

Schedule

- **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

- **Disclaimer:**
  - PJM **does not** favor one option over another 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

Components of an Energy Market Offer

Three components of a resource's offer:

- Start-up cost ($/start)
- Incremental energy cost ($/MWh)
- No-load cost ($/hour)

Determining Price and Dispatch

- **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

What Is 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.

Economic Dispatch Formulation

- 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

Economic Dispatch Formulation

Objective Function – Total Production Cost

$Minimize\ for\ all\ resources$:

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

System Balance

$$Total\ Generation - Total\ Load - Losses = 0$$

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

Border Adjustment Options Overview

- The border adjustment options can be for any border between two regions where one region has a carbon price and the other does not

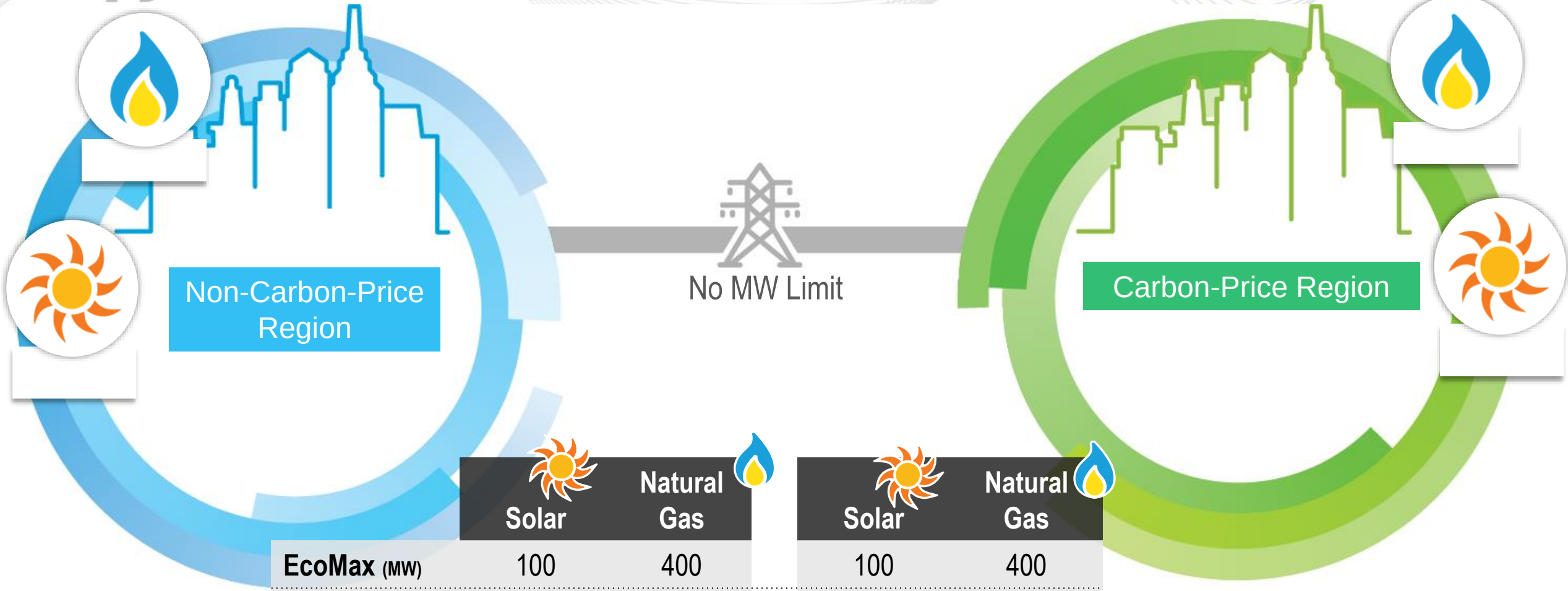
- The options will be presented using simple examples to help illustrate the concepts

Border Adjustment Options Disclaimer

- 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.

Example System



	Non-Carbon-Price Region		Carbon-Price Region	
	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

Unit Emissions Rates

- It is assumed that the carbon price is 1 $/short ton.

- Natural gas generators have the following emissions rates:
  - Natural Gas Generator in the carbon-price region = 80 short ton/MWh
  - Natural Gas Generator in the non-carbon-price region = 90 short ton/MWh

Carbon-Price Region Emissions Obligation

- 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)

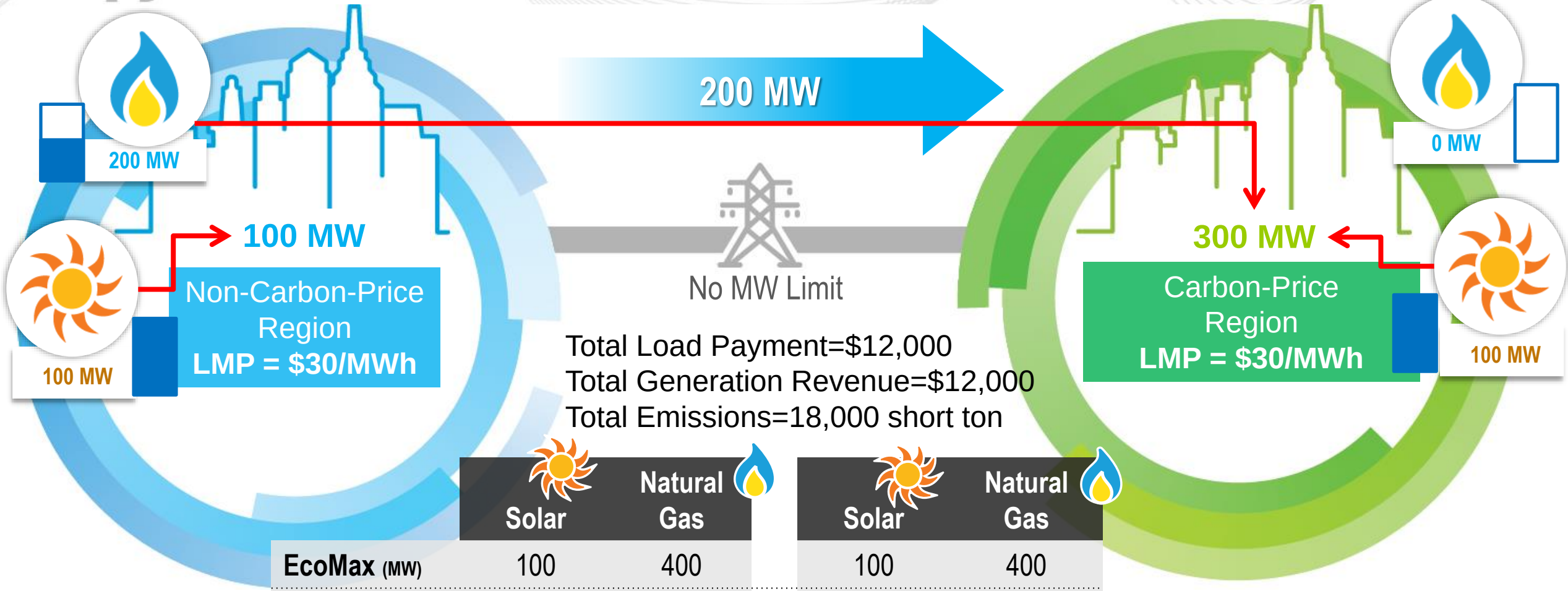
Dispatch Rules

- 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



Total Load Payment=$12,000
Total Generation Revenue=$12,000
Total Emissions=18,000 short ton

	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

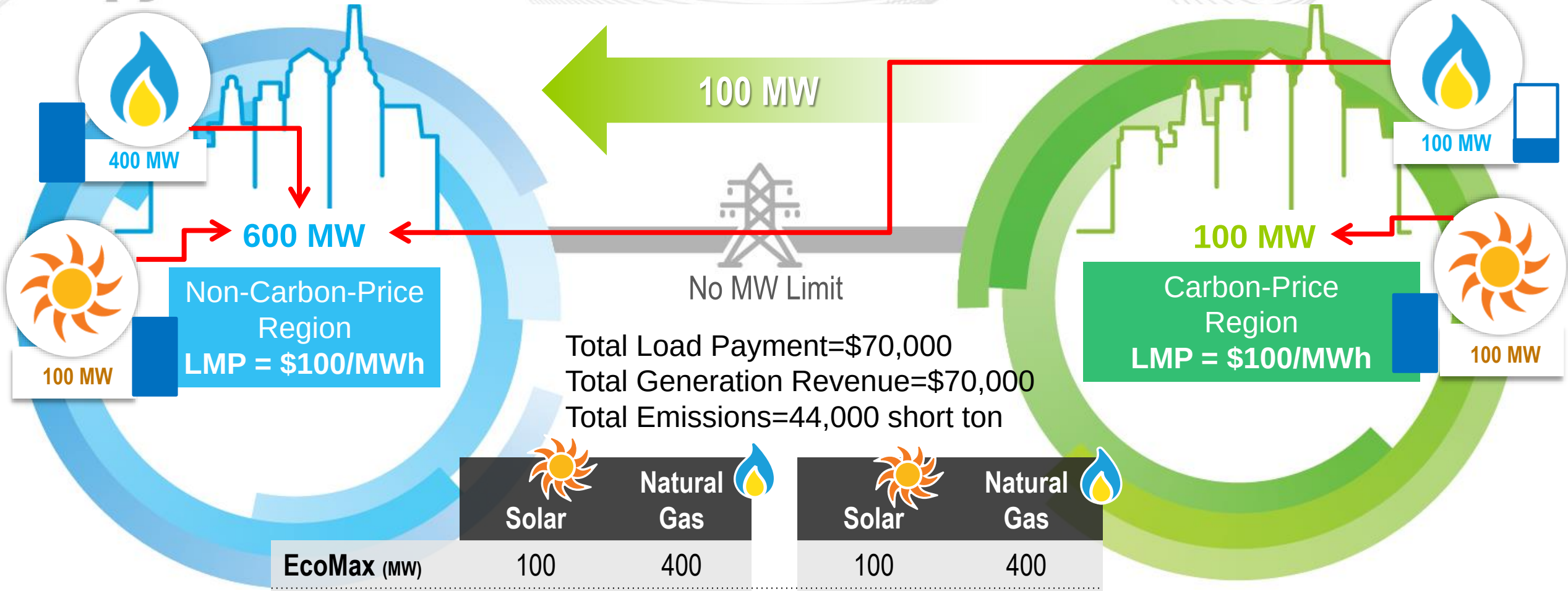
Example 1: Settlement

- 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



Total Load Payment=$70,000
Total Generation Revenue=$70,000
Total Emissions=44,000 short ton

	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

Example 2: Settlement

- 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

No Border Adjustment: Advantages and Disadvantages

- 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

Dispatch Rules

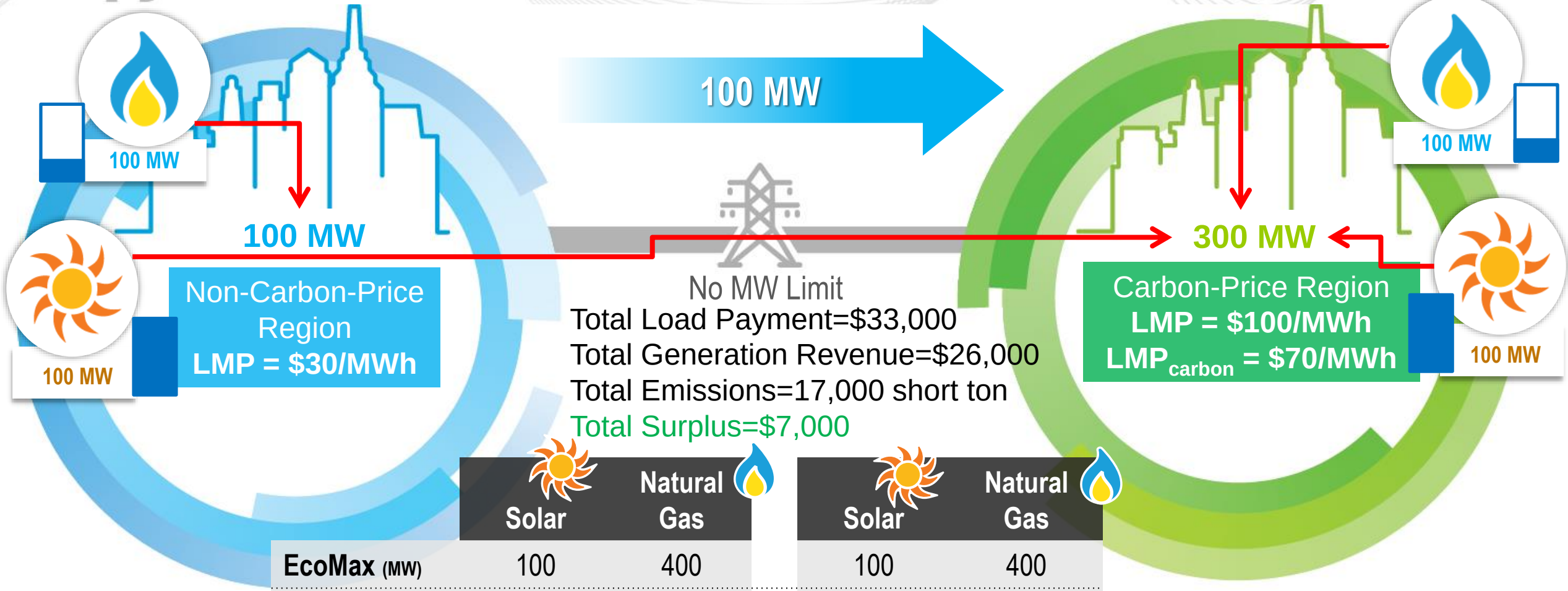
- Generators located in the carbon-price region
  - Dispatched using offers that include the cost of carbon

- 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



Total Load Payment=$33,000
Total Generation Revenue=$26,000
Total Emissions=17,000 short ton
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

Example 3: Settlement

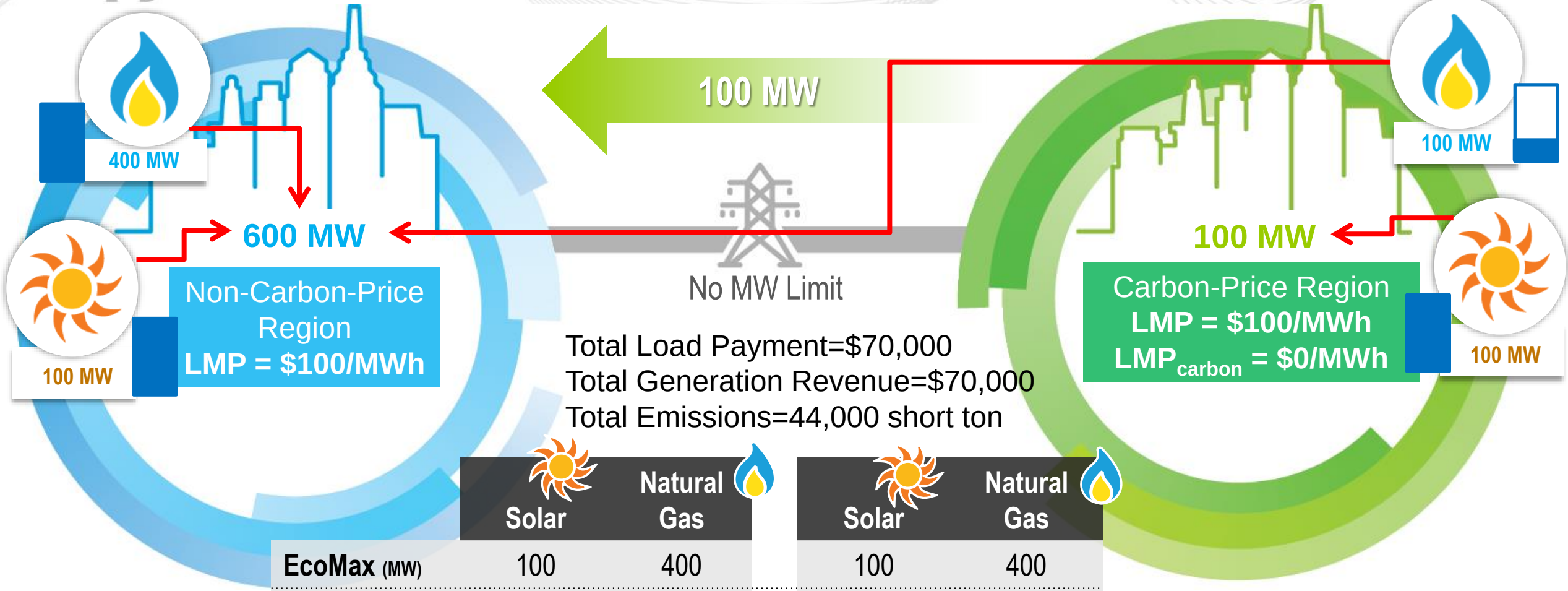
- Revenue Adequate:
  - Total Load Payments > Total Generator Revenue
  - Surplus $7,000 is allocated back to the carbon-price-region

- 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



Total Load Payment=$70,000
Total Generation Revenue=$70,000
Total Emissions=44,000 short ton

	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

Example 4: Settlement

- 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

One-Way Border Adjustment: Advantages and Disadvantages

- Advantages:
  - Revenue Adequate – may result in a surplus if there is a non-zero marginal cost of carbon compliance

    (Total Load Payments ≥ 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

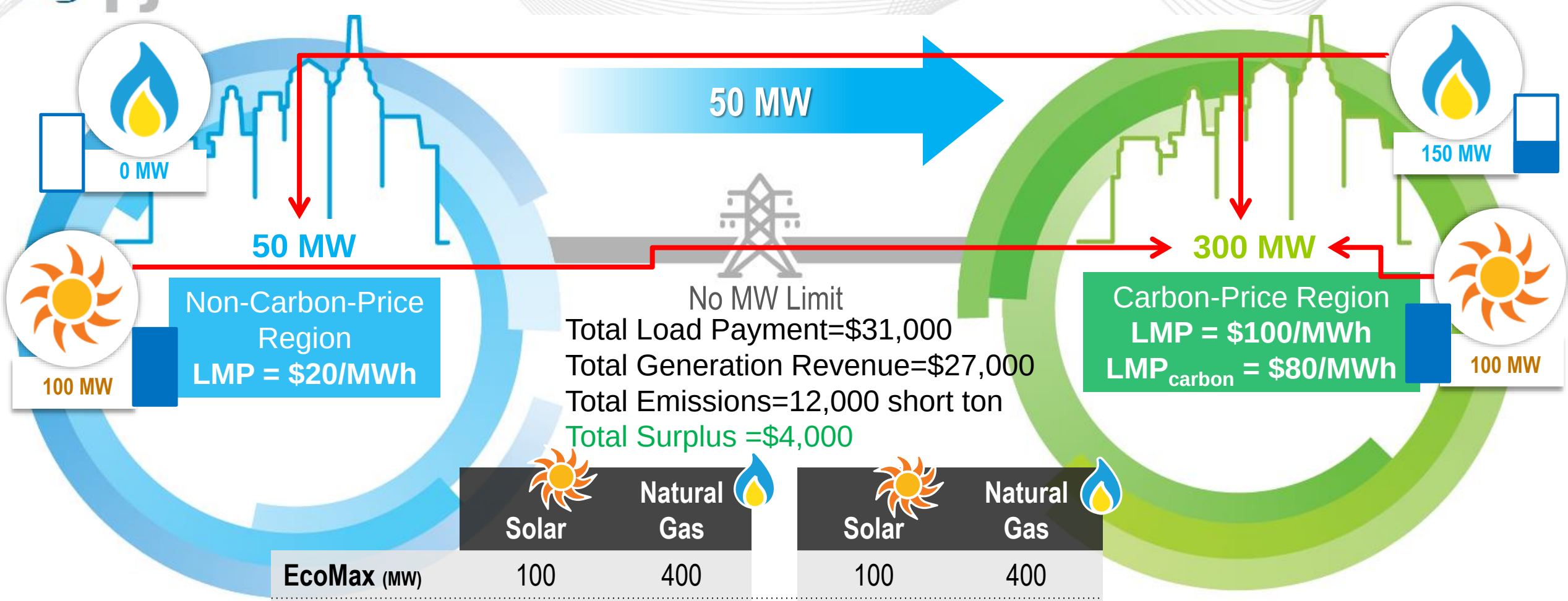
Dispatch Rules

- For all generators:
  - When associated with serving load in the non-carbon-price region
    - Dispatched using offers that 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



	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

Example 5: Settlement

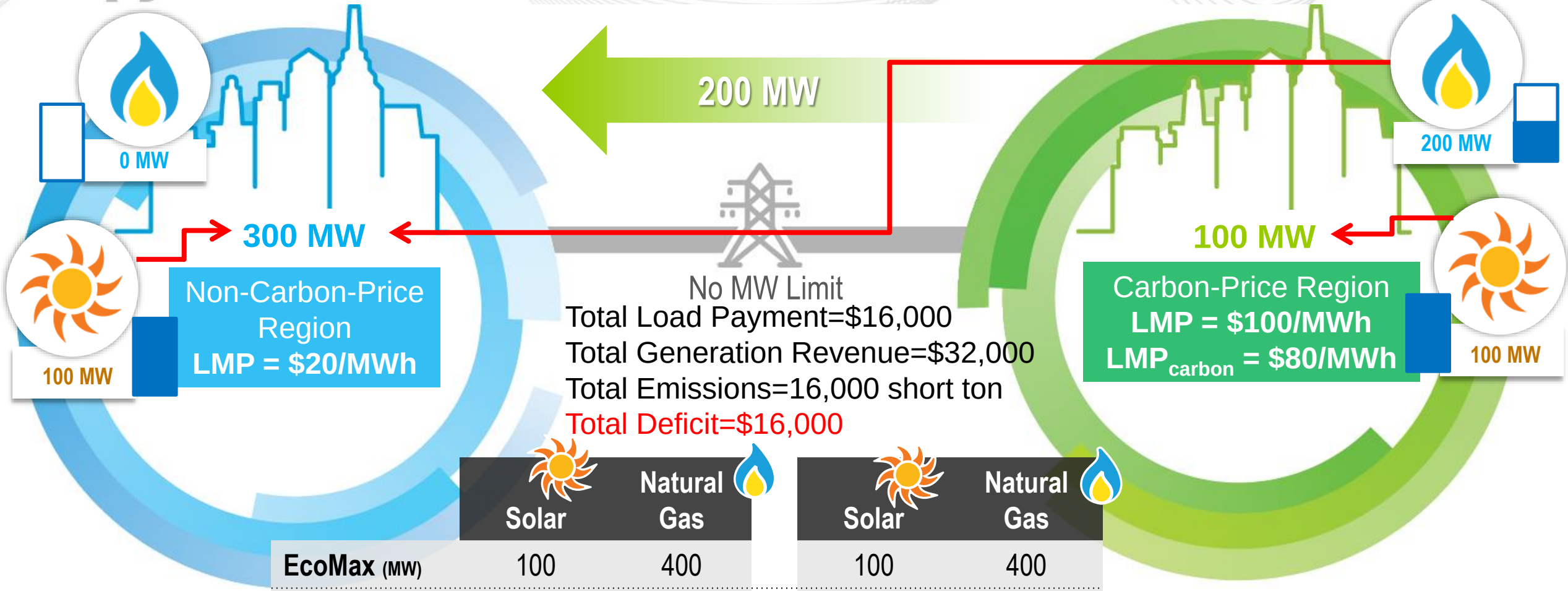
- Revenue Adequate:
  - Total Load Payments > Total Generator Revenue
  - Surplus $4,000 is allocated back to the carbon-price-region

- 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 Emissions=16,000 short ton
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

Example 6: Settlement

- 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

Two-Way Border Adjustment: Advantages and Disadvantages

- 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 ≤ Total Generator Revenues)