Emissions Trading, Point-of-Regulation and Facilities Sitting in Electric Markets

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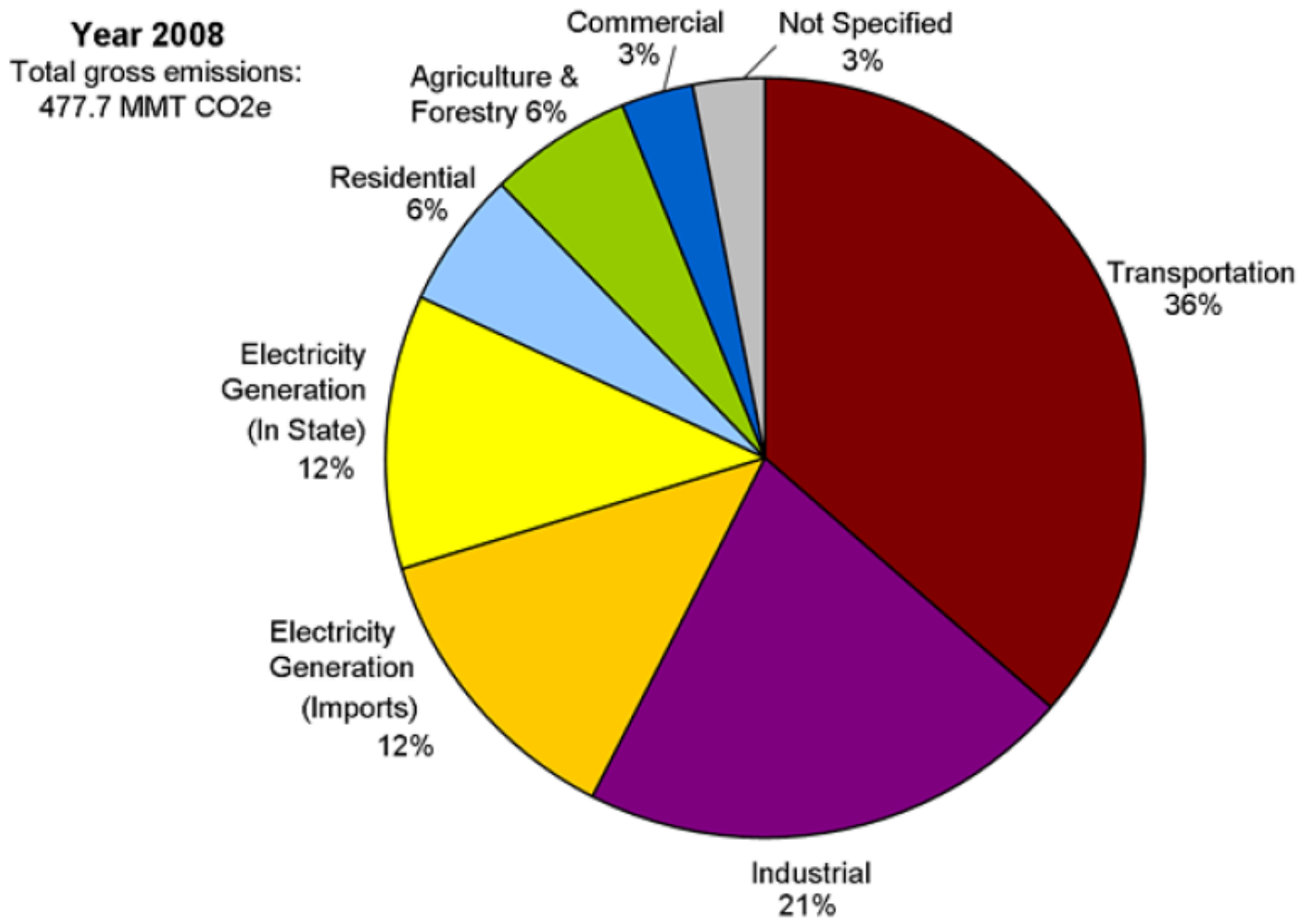
California's Efforts to Curb GHG

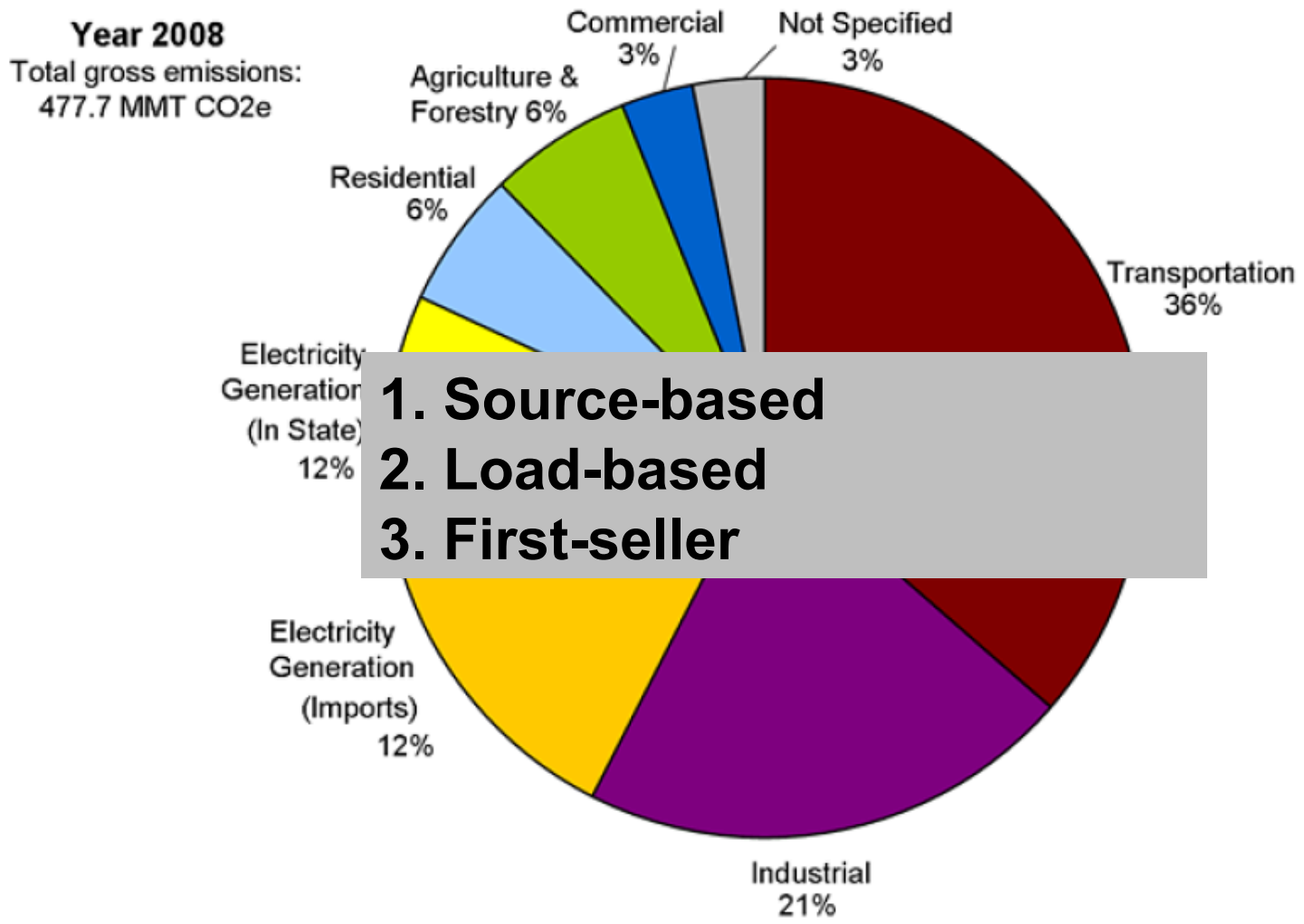
- The Global Warming Solutions Act of 2006 (Assembly Bill 32) to cap CA's GHG emissions at the 1990 level by 2020.
- Long-term goal – 80% below 1990 level by 2050.
- Cap on all major GHG sources
- Cap-and-trade programs are expected to begin in **2013**

CA GHG Emissions by Sectors



http://www.arb.ca.gov/cc/inventory/data/graph/graph.htm

CA GHG Emissions by Sectors



Emissions Trading Proposals – Point of Regulation

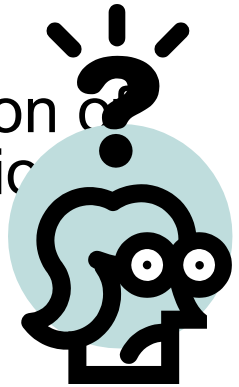
	Instate → Instate	Instate→Outstate	Outstate → Instate
Load-based	√ (LSE)		√ (LSE)
Source-based	√ (gen)	√ (gen)	
Modified Load-based	√ (LSE)	√ (gen)	√ (LSE)
Modified Source-based	√ (gen)	√ (gen)	√ (gen)
First-Seller	√ (gen)	√ (gen)	√ (LSE)

( ): point of regulation

Key Questions of the Long-run Analysis

- Previously in the INFRADAY conference…

- Pollution haven hypotheses: the permanent migration of polluting industries from locations with strict regulatio to locations with lessen environmental regulations [Condliffe, Morgan, 2008; Henderson, 1996]



- ***How will emissions trading with different points of regulation considered by the California government drive the facility sitting decisions & market outcomes in the long run?***
- ***Will the three proposals effectively mitigate emissions leakage in the long run?***

Assumptions of the Long-run Analysis

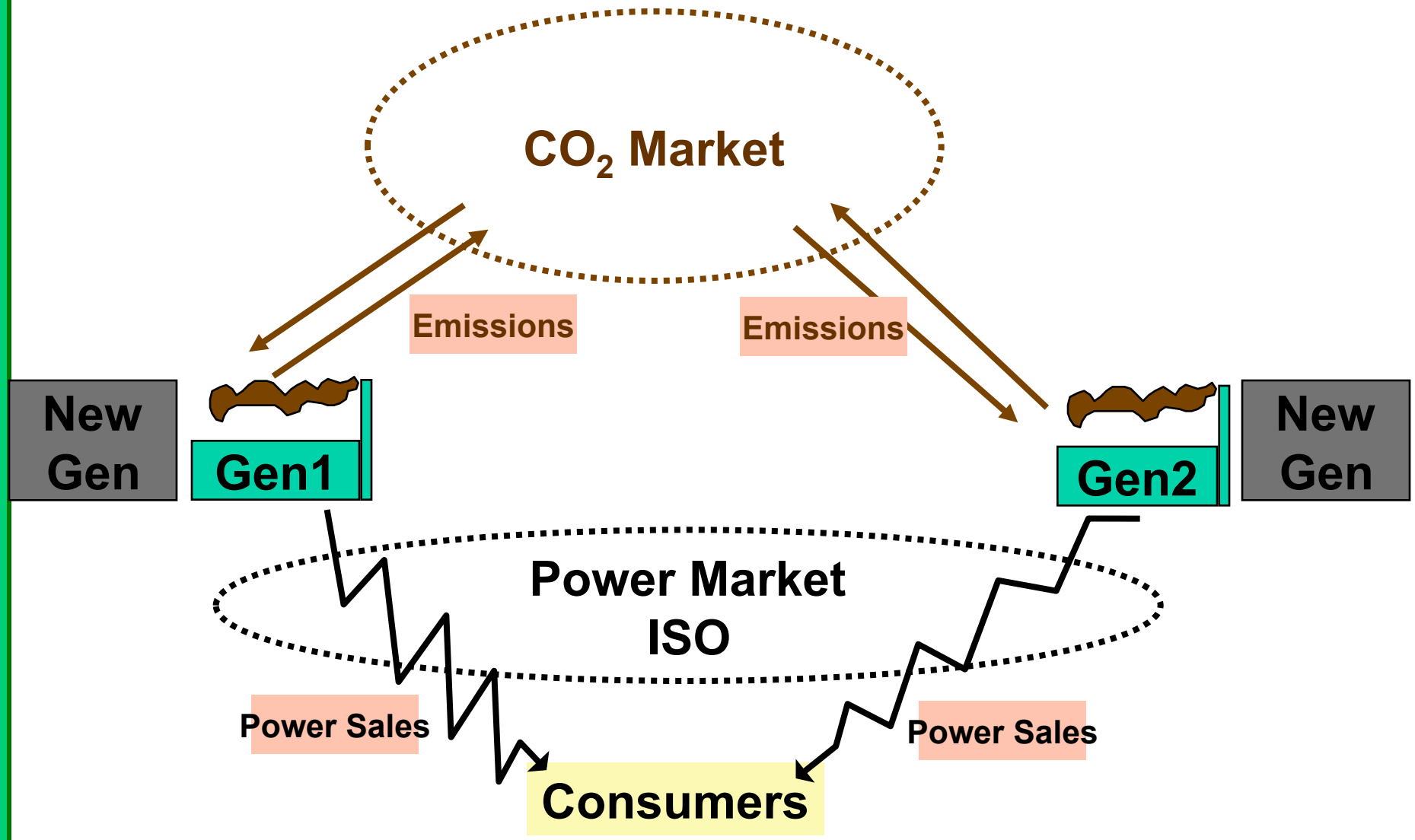
- Producers (price-takers) make the investment (capacity expansion) and operation decisions simultaneously when facing a deterministic load growth. Power sales are through Bilateral contracts
  - Individual open-looped formulation;
  - Close-looped social-planning's problem
- We consider three technologies:

Variable\technologies	Coal-fired	Combinded Cycle	Combustion turbines
Emission Rate [ton/MWh]	1	0.435	0.636
Varialbe Cost [$/MWh]	14.2	38.4	57.2
Levelized Cost [$/MWh]	19	10.6	10.2

Source: National Energy Modeling System (NEMS)

- Load grows to 2 times of the short-run study while the transmission infrastructure remains unchanged.
- Not explicitly model retirement decision.

Source-Based Market Schematic



Source-Based: Producer & Consumer Model

Producers g_{fij} = amount of power sold to LSE *j* by firm *f* in node *i* [MWh]

x_{fit} = firm *f* new capacity type *t* in location *i* [MW]

Revenue Operation Cost New Capacity Cost

$$MAX_{\{g_{if},x_{fit}\}} \sum_j [(p_j - w_j)(\sum_i g_{fij})] - \sum_i [(C_{fi} - w_i)(\sum_j g_{fij})] - \sum_{i,t} C_t^{New} x_{fi,t}$$

$$-p^{CO2}(tot_f^{CO2} - K_f)$$

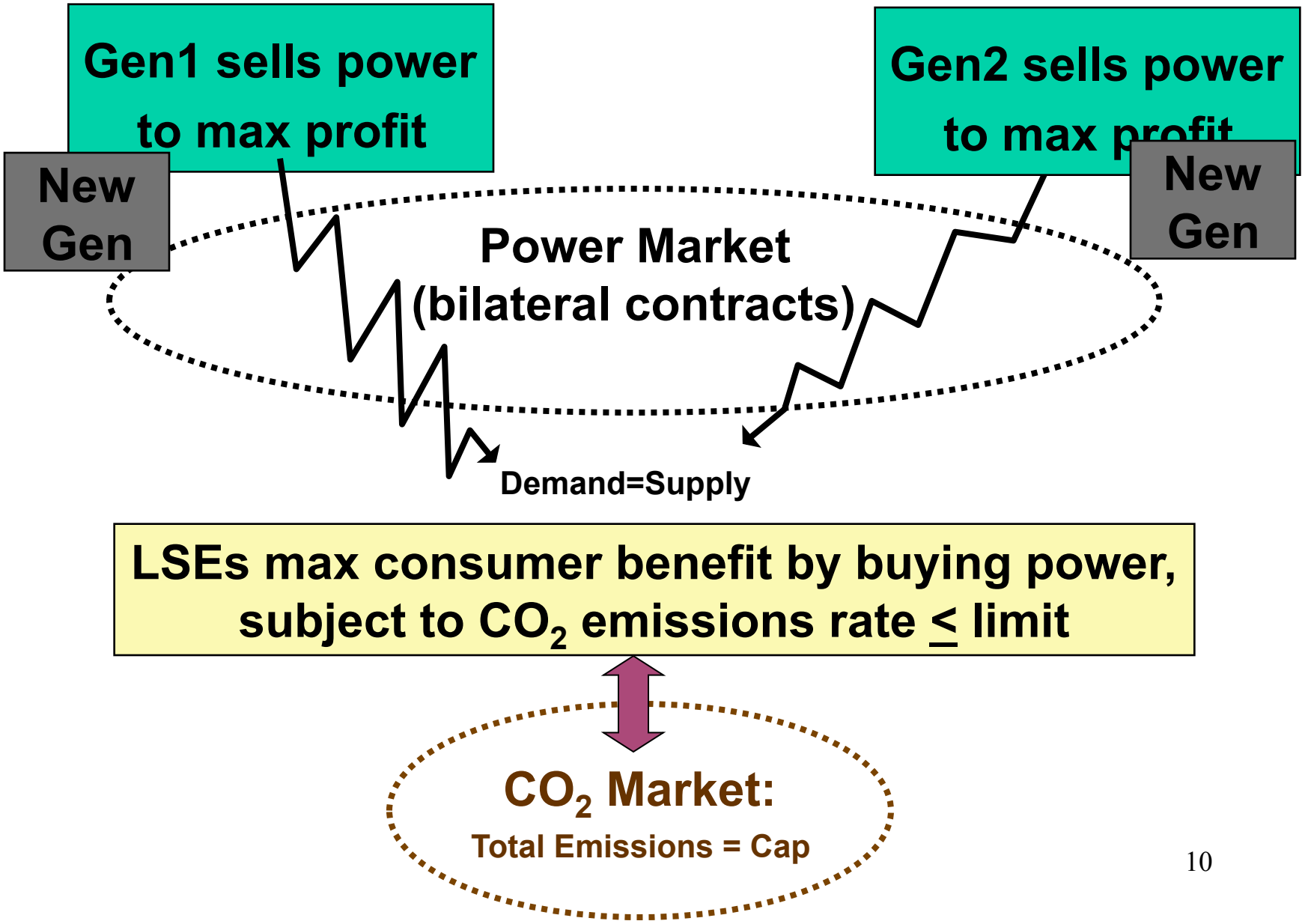
$$s.t.: \sum_j g_{fij} \le CAP_{fi}, \forall i$$

$$g_{fij} \ge 0, \forall i, j$$

Consumers/LSE

$$p_j = P_j^0 - \frac{P_j^0}{Q_j^o}(\sum_{f,i} g_{fij}), \forall j$$

Load-Based Market



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$$s.t.: \sum_j g_{fij} \le CAP_{fi}, \forall i$$

$$g_{fij} \ge 0, \forall i$$

Consumers/LSE z_{fij} **:LSE *j* purchase power generated by firm *f* in node *i***

$$MAX_{z_{fij}} P_j^0(\sum_{fi} z_{fij}) - \frac{P_j^0}{2Q_j^o}(\sum_{fi} z_{fij})^2 - \sum_{fi} \bar{p}_{fij} z_{fij}$$

$$-p^{CO2}(tot_j^{CO2} - K_j)$$

$$s.t.: z_{fij} \ge 0$$

$\bar{p}_{fij}$: $ per MWh paid by LSE to generators

Load-Based: Producer & Consumer Model

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$$-p^{CO2}(tot_j^{CO2} - K_j)$$

$$s.t.: z_{fij} \ge 0$$

$\overline{p}_{fij}$: $ per MWh paid by LSE to generators

FOC: $$0 \le z_{fij} \perp -P_j^o + \frac{P_j^0}{Q_j^0}(\sum_{fi} z_{fij}) + \overline{p}_{fij} + p^{CO2} E_{fi} \ge 0, \forall z_{fij}$$

$$z_{fij} > 0, p_j = P_j^o - \frac{P_j^0}{Q_j^0}(\sum_{fi} z_{fij}) = \overline{p}_{fij} + p^{CO2} E_{fi}$$

p_j: Electricity price

Load-Based: Producer & Consumer Model

Producers g_{fij} = power sold to LSE *j* by firm *f* in node *i* [MWh]

x_{fit} = firm *f* new capacity type *t* in location *i* [MW]

$$MAX_{\{g_{if},x_{fit}\}} \sum_j [\overbrace{\left(p_j - w_j\right)\left(\sum_i g_{fij}\right)}^{\text{Revenue}}] - \overbrace{\sum_i [(C_{fi} - w_i)(\sum_j g_{fij})]}^{\text{Cost}} - \overbrace{\sum_{i,t} C_t^{New} x_{fit}}^{\text{New Capacity Cost}}$$

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$\$$ per MWh paid by LSE to generators

$$s.t.: z_{fij} \ge 0$$

FOC: $0 \le z_{fij} \perp -P_j^o + \frac{P_j^0}{Q_j^0}\left(\sum_{fi} z_{fij}\right) + \overline{p}_{fij} + p^{CO2} E_{fi} \ge 0, \forall z_{fij}$

$$z_{fij} > 0, p_j = P_j^o - \frac{P_j^0}{Q_j^0}\left(\sum_{fi} z_{fij}\right) = \overline{p}_{fij} + p^{CO2} E_{fi}$$

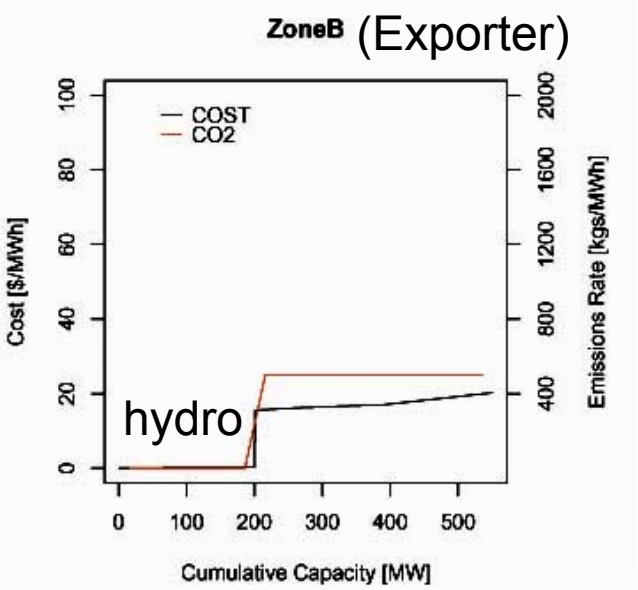
Electricity price

OR $z_{fij} > 0, \overline{p}_{fij} = p_j - p^{CO2} E_{fi}$

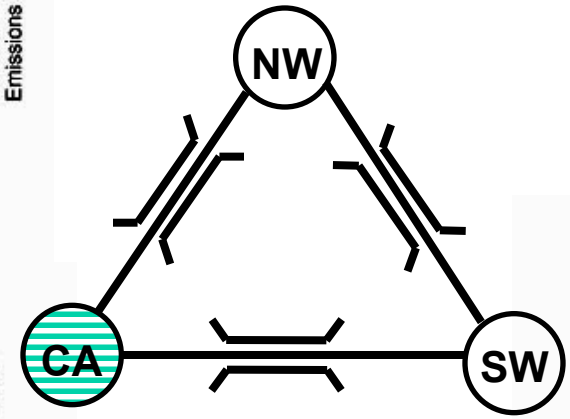
Analytical Conclusions

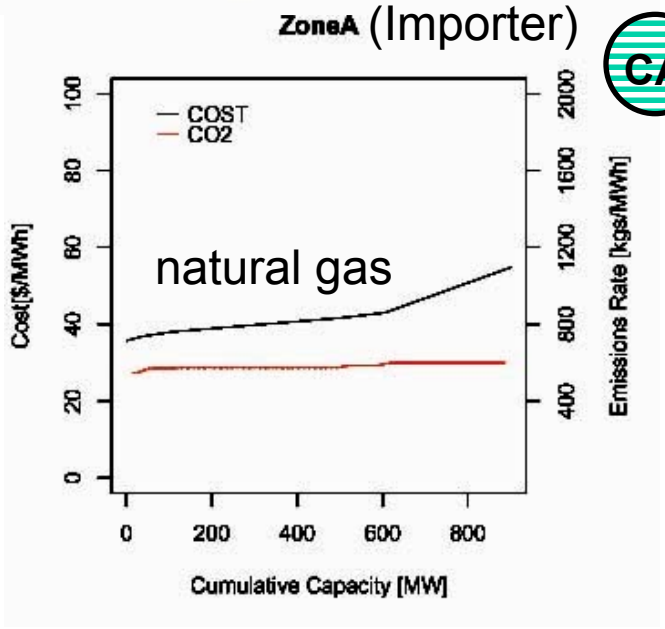
- Do the 3 proposals lead to different emissions permits and electricity prices and new capacity distributions in the long run?
  - *NO: Modified Load-based, Modified Source-based, & First-seller yield the same prices and capacity distribution*
- Solutions of individual open-looped formulation = close-looped social planner's problem
- *Caveats:*
  - Load-based introduces no inefficiencies into CAISO markets or power trading as a result of bundling emissions & energy;
  - Ignore other factors that affect sitting decisions, e.g., resource constraints, transmission lines, etc.

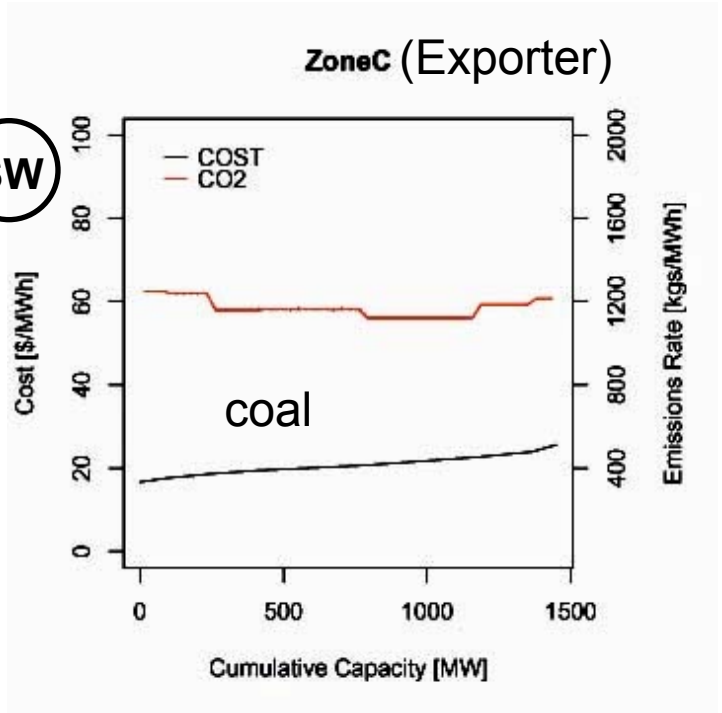
Numeric Example: Network, Gen Mix and CO_2 Emissions



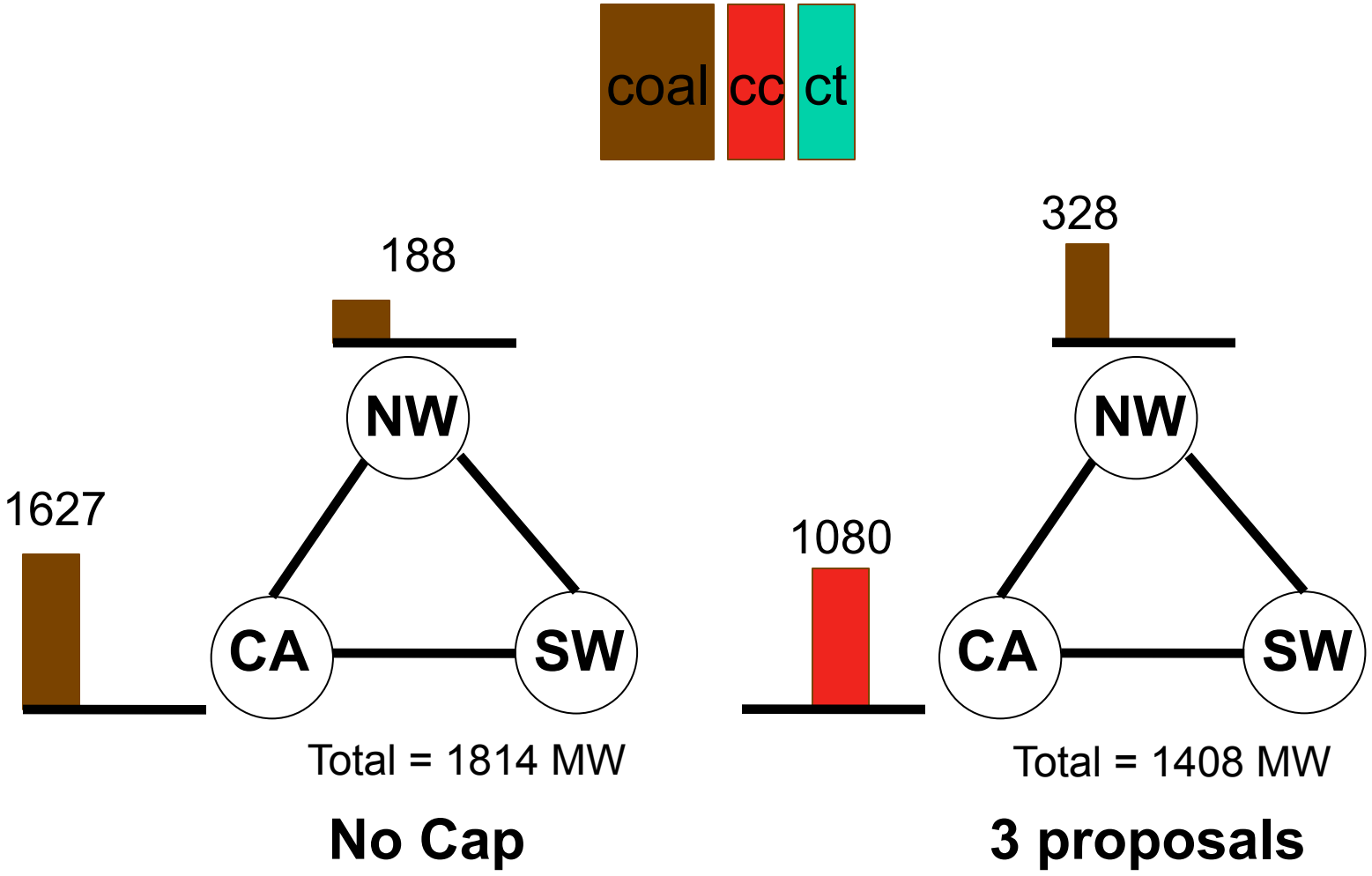
- ***Policy for Zone CA: Target of 600 tons***
- ***Total 10 units 3 zones***



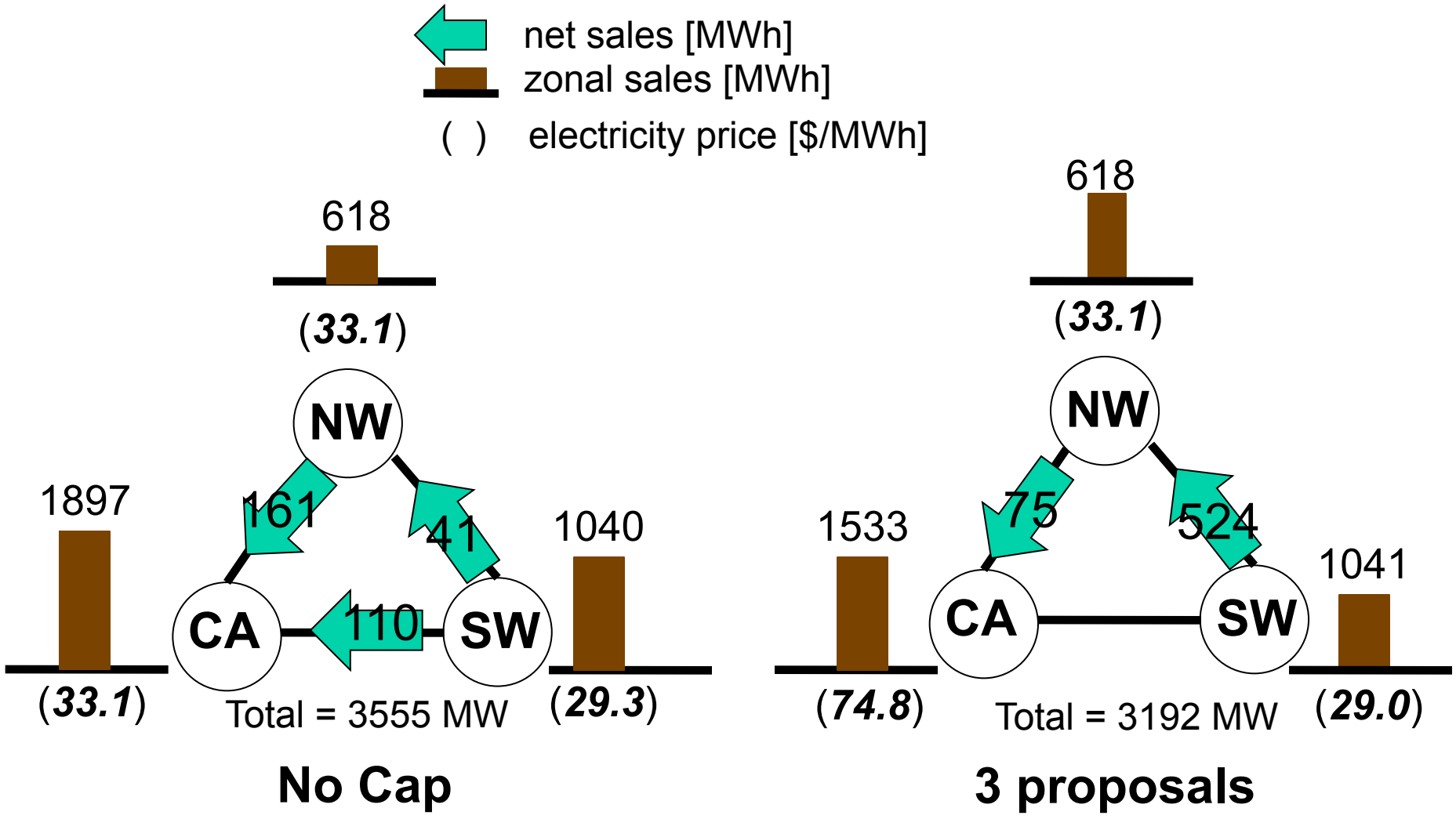




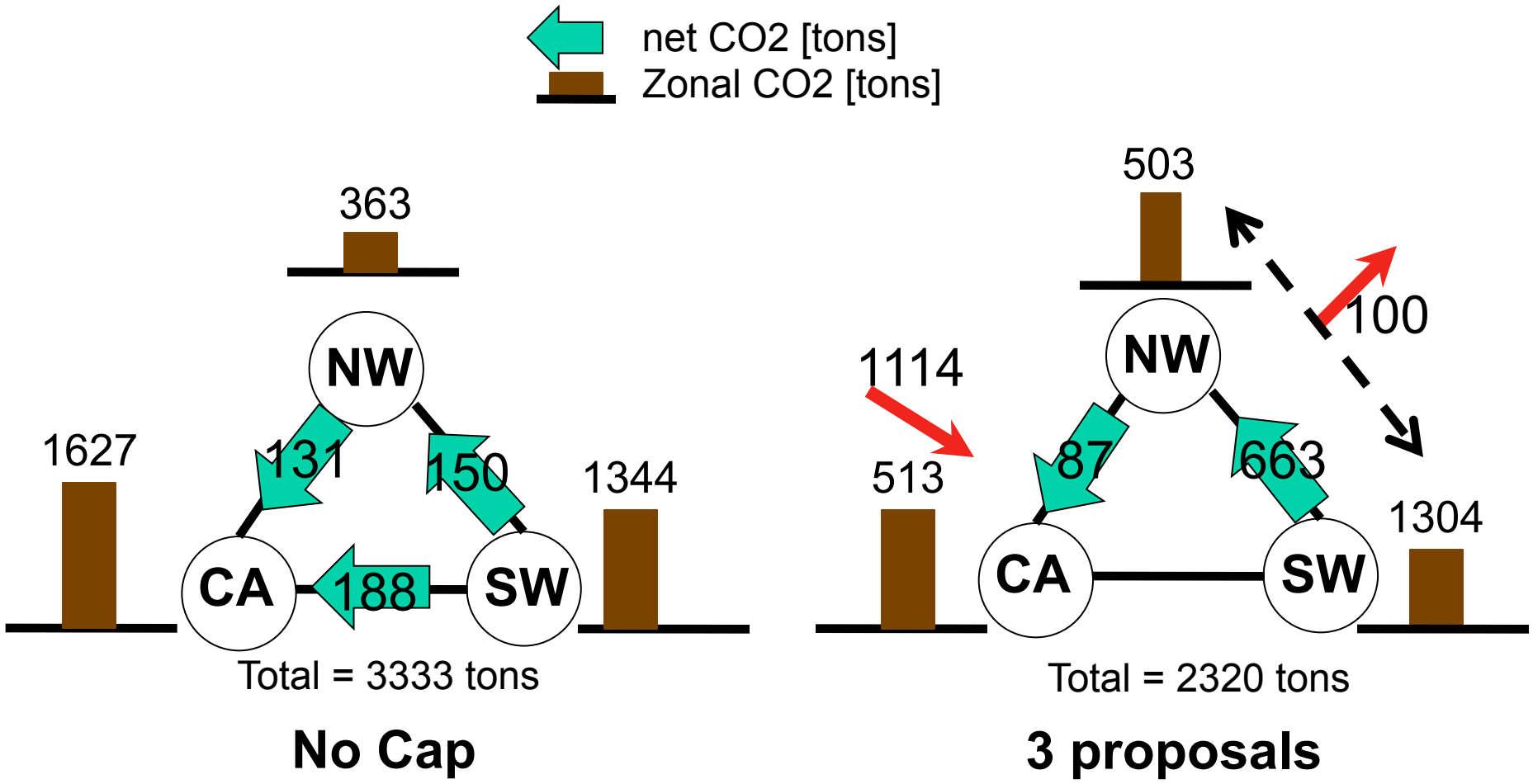
Results: Capacity Sitting Choices



Results: Electricity Sales

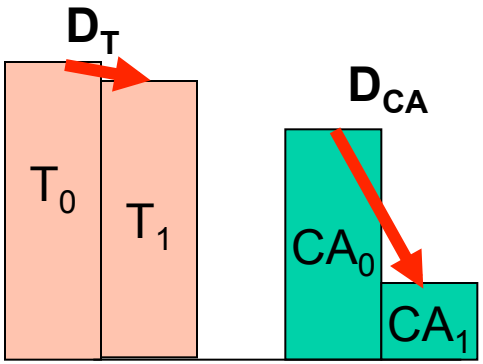


Results: CO_2 Emissions



Results: CO_2 Leakage

CO_2 leakage: % of credited CO_2 reductions that are not real



T_0: total emissions | no cap
T_1: total emissions | policy
CA_0: CA's credited emissions | no cap
CA_1: CA's credited emissions | policy

%leakage = 100%(1 - D_T/D_{CA})
= 100% (1- 1031/1346) = 25%

Results: Social Welfare

	3 Proposals	No Cap
Cap [tons]	600	N/A
Consumers Surplus [$]	356,176	397,588
Producers Surplus [$]	46,090	53,163
ISO [$]	4,008	576
Social Welfare [$]	406,274	451,327
Construction cost [$]	17,677	N/A
***Cost of Regulation [$]**	17,582	N/A
CO2 [$/ton]	99.47	N/A

Calculation assumes that consumers initially own all allowances

Allowance rent = $99.47 [$/ton]*600 [tons]= $59,682

If produces retain all the emission rent, the consumers' surplus will reduce to $296,494, while producers' surplus increases to $105,772

*: solve for a linear program with fixed demand

Conclusions

- If economic rent of allowances is retained by consumers, three proposals are economically equivalent (nodal prices, consumer costs, social surplus, etc) in long-run.
- Polluting facilities will be sited in other states with less stringent polices.
- All proposals are still subject to CO_2 leakage due to contract shuffling but to a less extent in long run.
- Finding local solutions to regional/global problems remains challenging.
- Careful consideration is needed to mitigate emission leakage and price impacts.

References & Ongoing Work

- **[Condliffe, Morgan, 2008]** The effects of air quality regulations on the location decisions of pollution-intensive manufacturing plants, *Journal of Regulatory Economics*, 36 (1): 83-93.
- **[Chen, Liu, Hobbs, 2011]** Economic and Emissions Implications of Load-based, Source-based and First-seller Emissions Trading Programs under California AB32, *Operations Research*, 59(3): 696-712.
- **[Henderson, 1996]** Effects of air quality regulation. *American Economics Review*, 86(4):789- 831.
- **[Chen, Liu, 2011]** Emissions Trading, Point-of-Regulation and Facilities Sitting in Electric Markets, Working paper, University of California Merced.
- **[Bushnell, Chen, 2011]** Regulation, Allocation and Leakage in Cap-and-Trade Markets for CO2, *Resources and Energy Economics* (under review)

- **Large-scale simulation of the western electricity grid in order to quantify the extent of emission leakage and price impacts under various policy choices.**

Thank you!

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