Electricity Industry Restructuring and ISO Markets in the US

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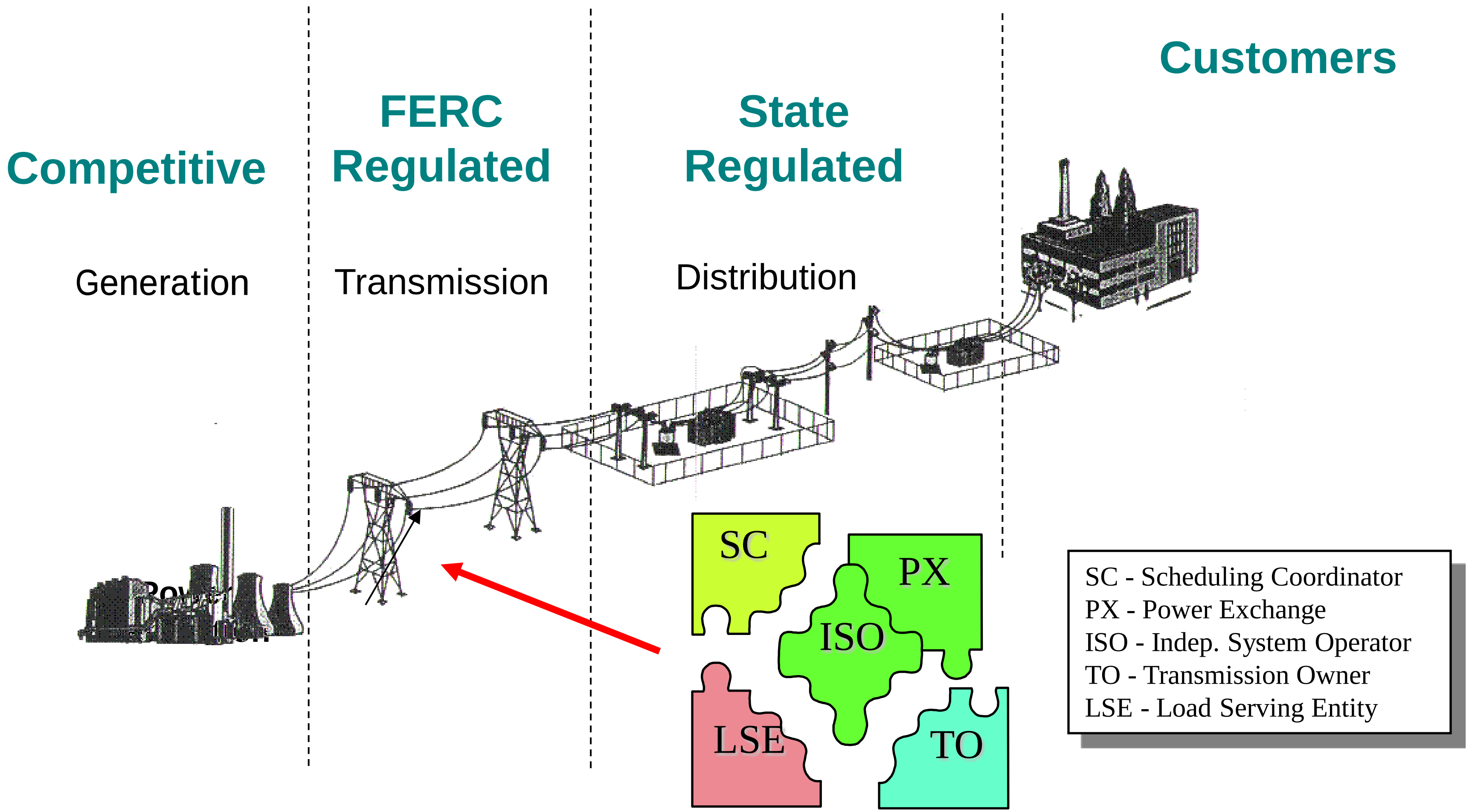
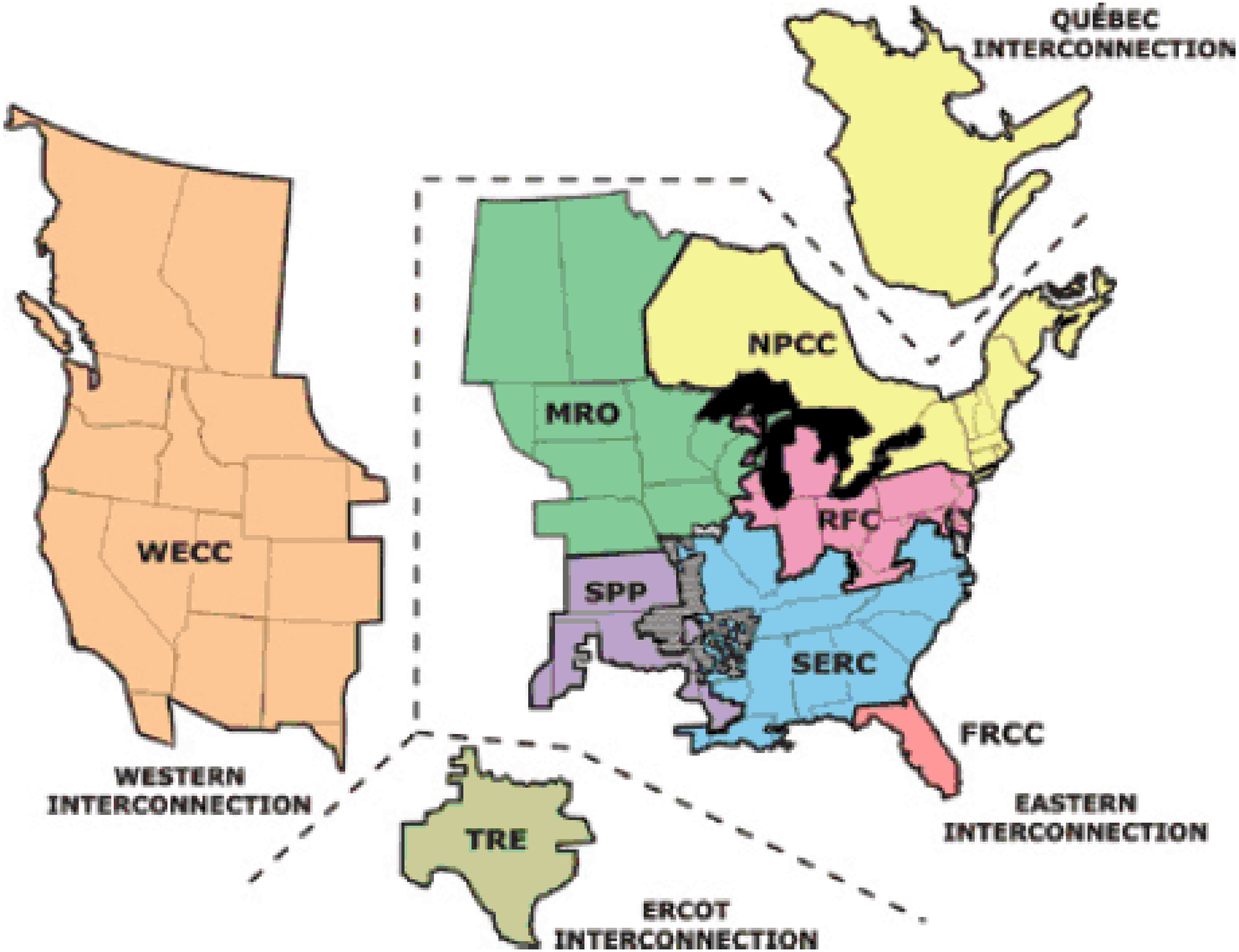
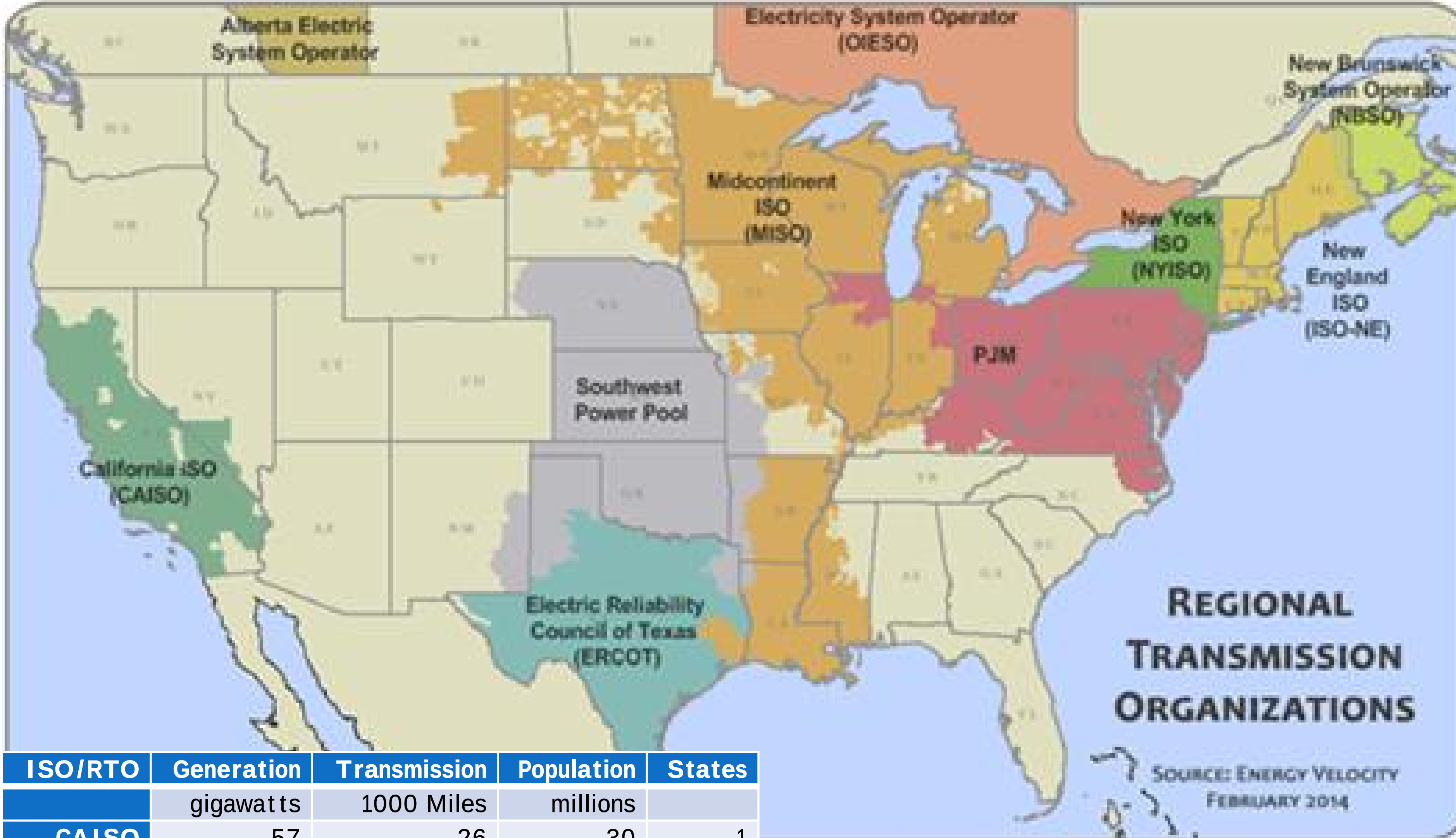
POWER INDUSTRY RESTRUCTURING



Interconnection Regions



Source: NERC, 2009



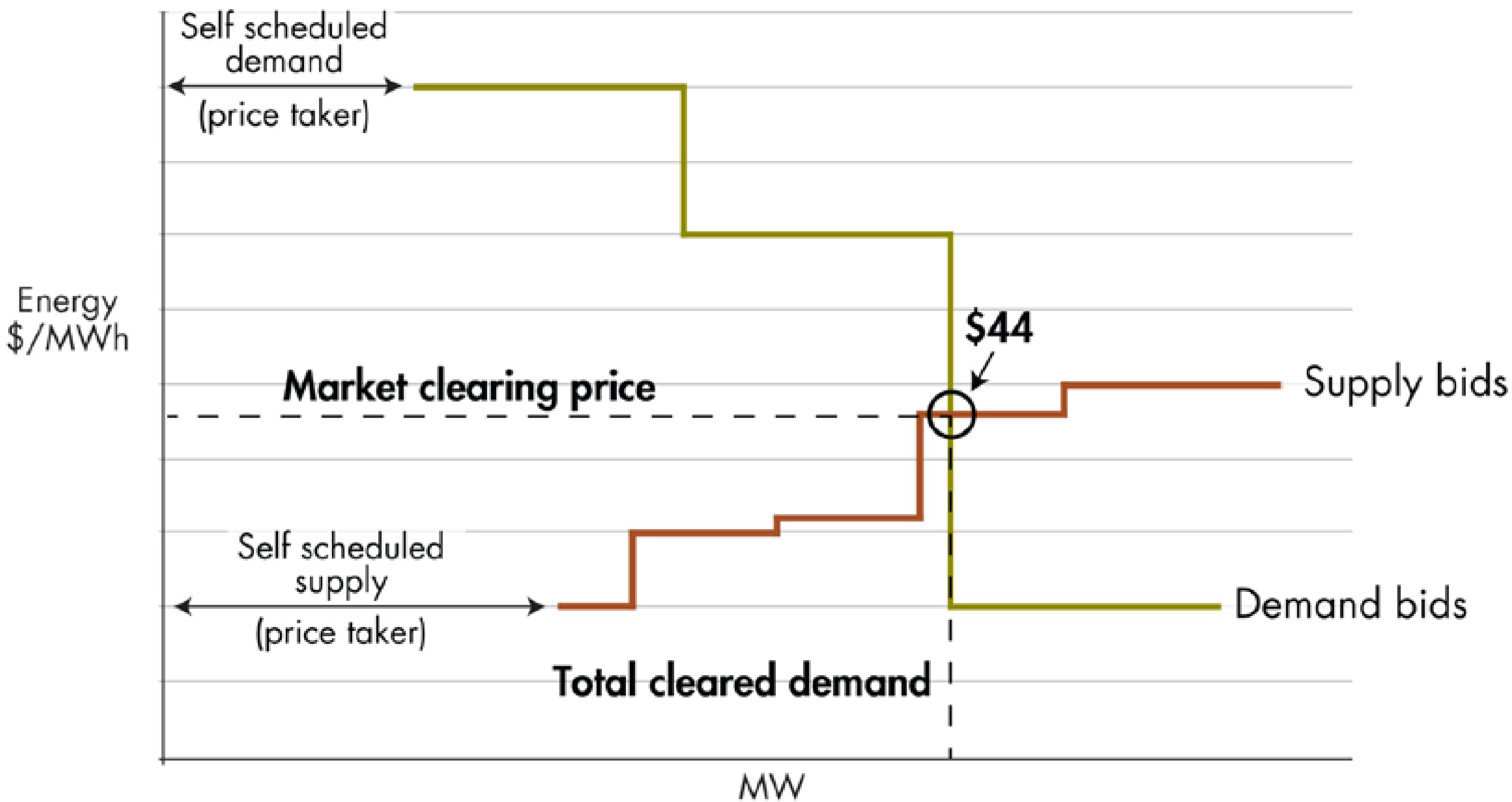
ISO/RTO	Generation	Transmission	Population	States
	gigawatts	1000 Miles	millions	
CAISO	57	26	30	1
ISO-NE	34	8	14	6
MISO	201	66	53	15
NYISO	41	11	19	1
PJM	165	56	51	13
SPP	66	51	15	6
ERCOT	70	40	23	1
TOTAL	634	256	205	43

Cover 70% of US load

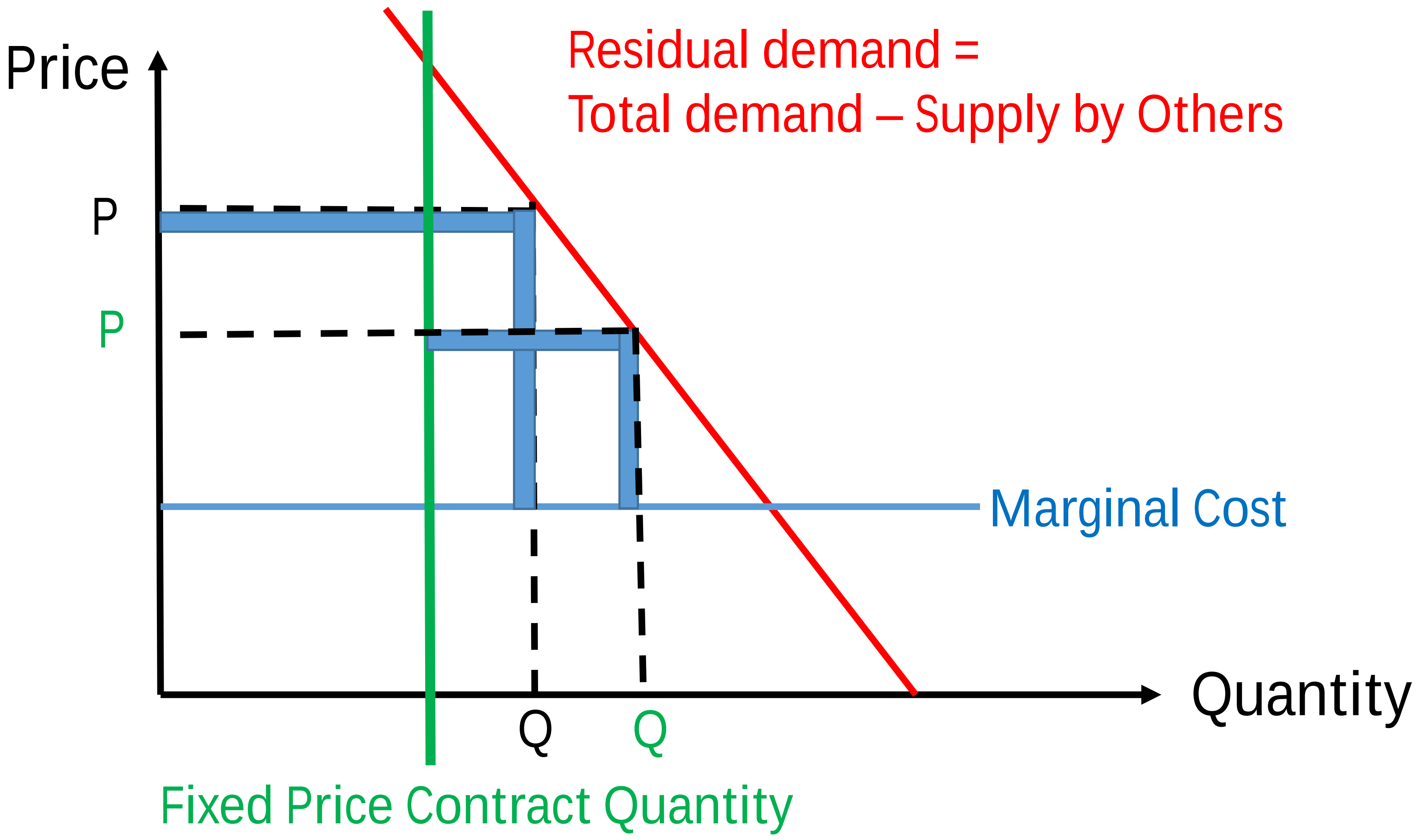
Smart Market Design

- Bid Based (subject to market power mitigation)
- Market clearing respects all technical constraints
- Market clearing is based on optimization software that minimizes “as bid social cost” (max social welfare) subject to technical constraints
- Whole sale prices based on locational marginal price (LMP)

Uniform market clearing prices



Forward Contracting



Market Monitoring and Market Power Mitigation

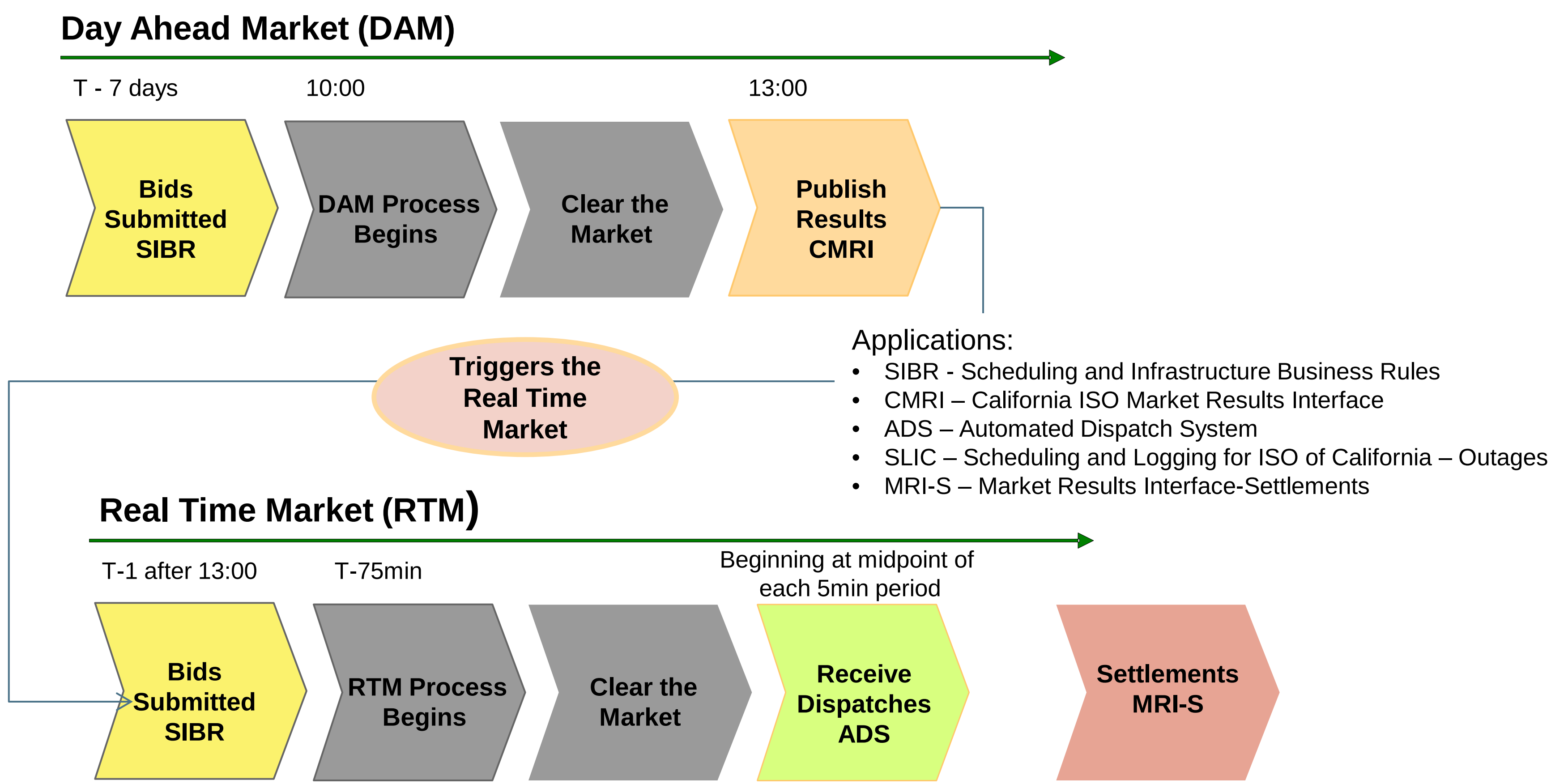
- Each ISO has a Market Monitoring unit (either internal or external) which is paid for by the ISO but is independent and reports to FERC.
- Functions of the Market Monitoring unit
  - Conducts ongoing empirical analysis of market data
  - Publishes quarterly and annual report on the state of the market
  - Submits opinions to the ISO staff on market design modifications
  - Develops (subject to FERC approval) and implements market mitigation protocols including dynamic screening and mitigation of energy bids, and price caps on various bid components.
  - Monitors participants' behavior in all ISO markets and files complaints with FERC enforcement division if they detect price manipulation attempts. (in 2013 JPMorgan settled an electricity market manipulation case with FERC for $410 million penalty)

System and Market Operation

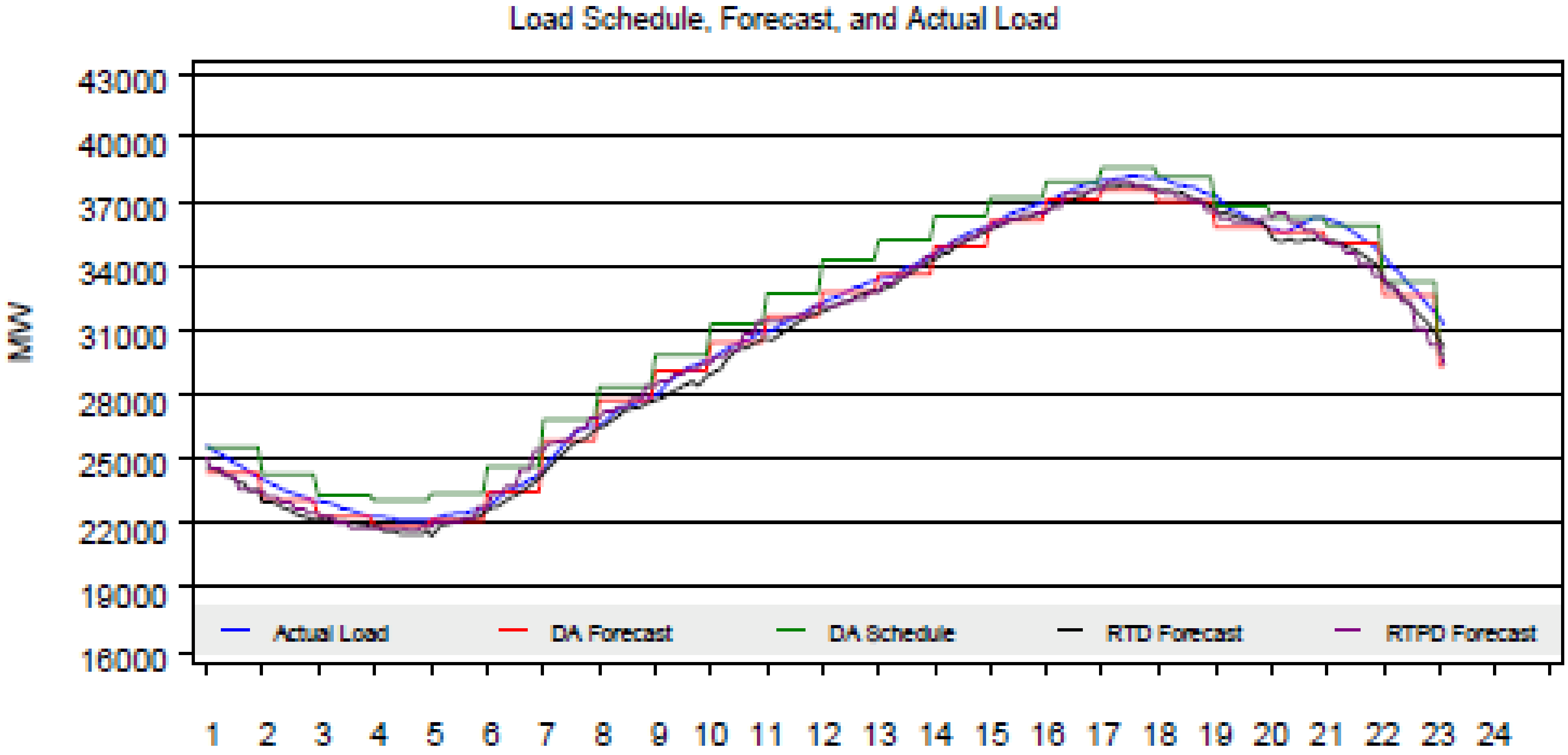
Multiple Products and Markets

- Day-ahead energy market
- Real-time energy market
- Forward capacity market
- Financial transmission rights (FTR, CRR) auction market
- Regulation market (capacity and mileage)
- [Flexible Ramping Product]
- Operating reserves markets
  - Spinning
  - Non-spinning
  - Replacement

California ISO Market Timeline



Typical Daily Scheduling



Two-settlements Electricity Markets

- The two-settlement electricity markets consist of two interrelated markets: day-ahead (DA) market, and real-time (RT) market.
- DA LMPs are generally considered more stable than RT LMPs.
- The DA market includes three sequential processes: market power mitigation and reliability requirement determination (MPM-RRD), integrated forward market (IFM), and residual unit commitment (RUC).
- In the RT market, the ISO runs the economic dispatch process every 5 minutes to rebalance the residual demand.
- If a resource does not cover its total cost including start-up and minimum load cost through its energy revenue at DA and RT LMPs, its shortfall is covered by an uplift payment which is allocated to market participants.

Unit Commitment Optimization - MIP
(Solved for 24 hours in Day Ahead market)

Decisions (financially binding):

on/off , output level and compensated reserves for each unit in each of 24 hours + locational marginal energy prices and reserve prices for each node and hour

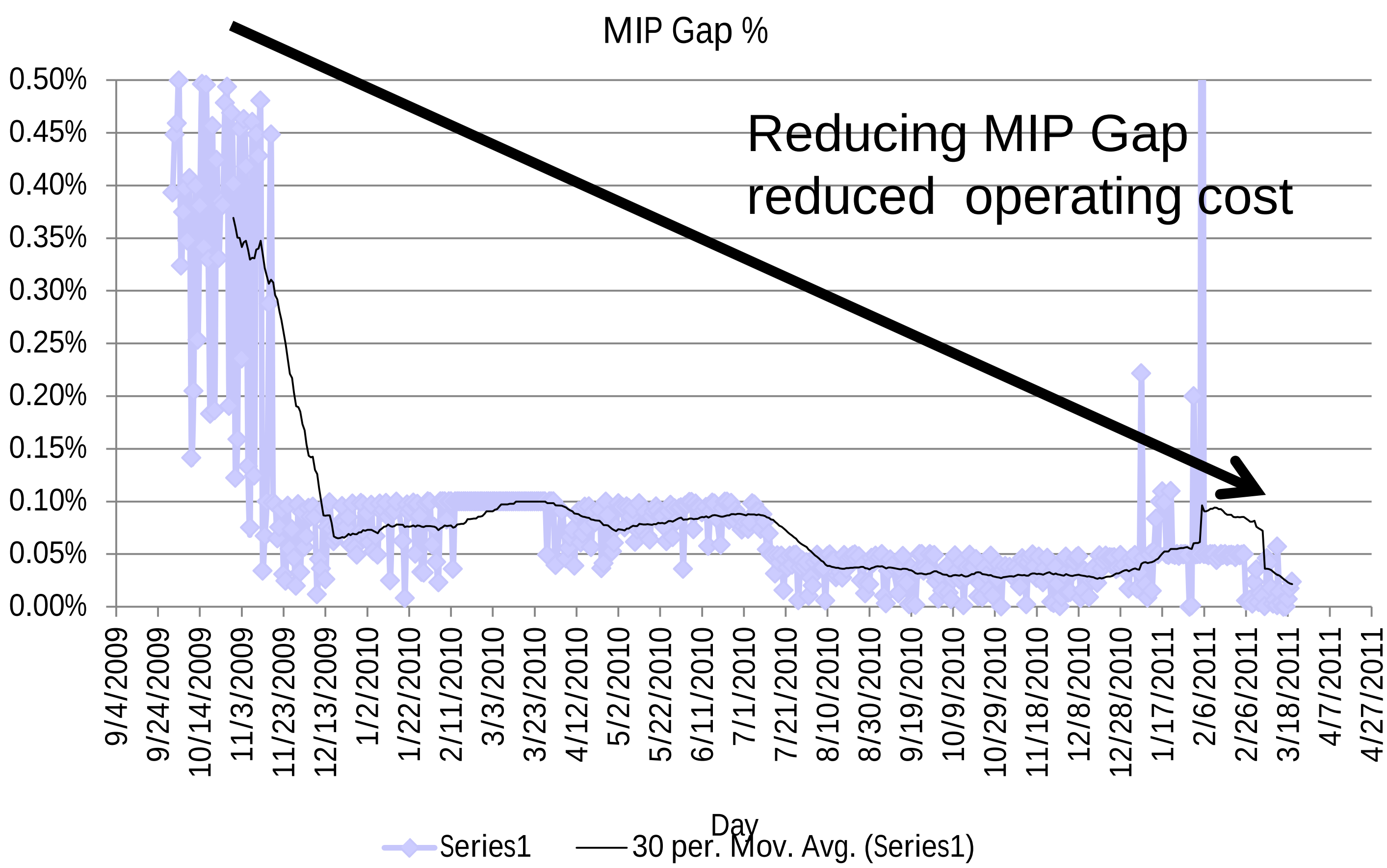
- *Minimize S* ***(fuel cost + no-load cost + startup cost)***

  s.t.

  - **Load balance constraint at each node**
  - **Unit output constrain for each generator**
  - **Unit ramping limits for each gen**
  - **Unit min up time and min down time for each gen**
  - **Transmission constraints (DC approximation with thermal proxy limits)**
  - **Reserves margin requirements**
  - **Contingencies (n-1)**

(Cost and constraints data provided as offers in day ahead auction)

Mixed Integer Programming reduced annual operating costs by estimated $23 million



Power Flow Optimization (every five minutes) and Locational Marginal Pricing (LMP) For Generators that are Running and Synchronized

Decisions:

Price of energy (LMP) at node i = Marginal cost of energy at the node Calculated as the dual variable to energy balance constraint for the node in a linearized Optimal Power Flow approximation (DCOPF)

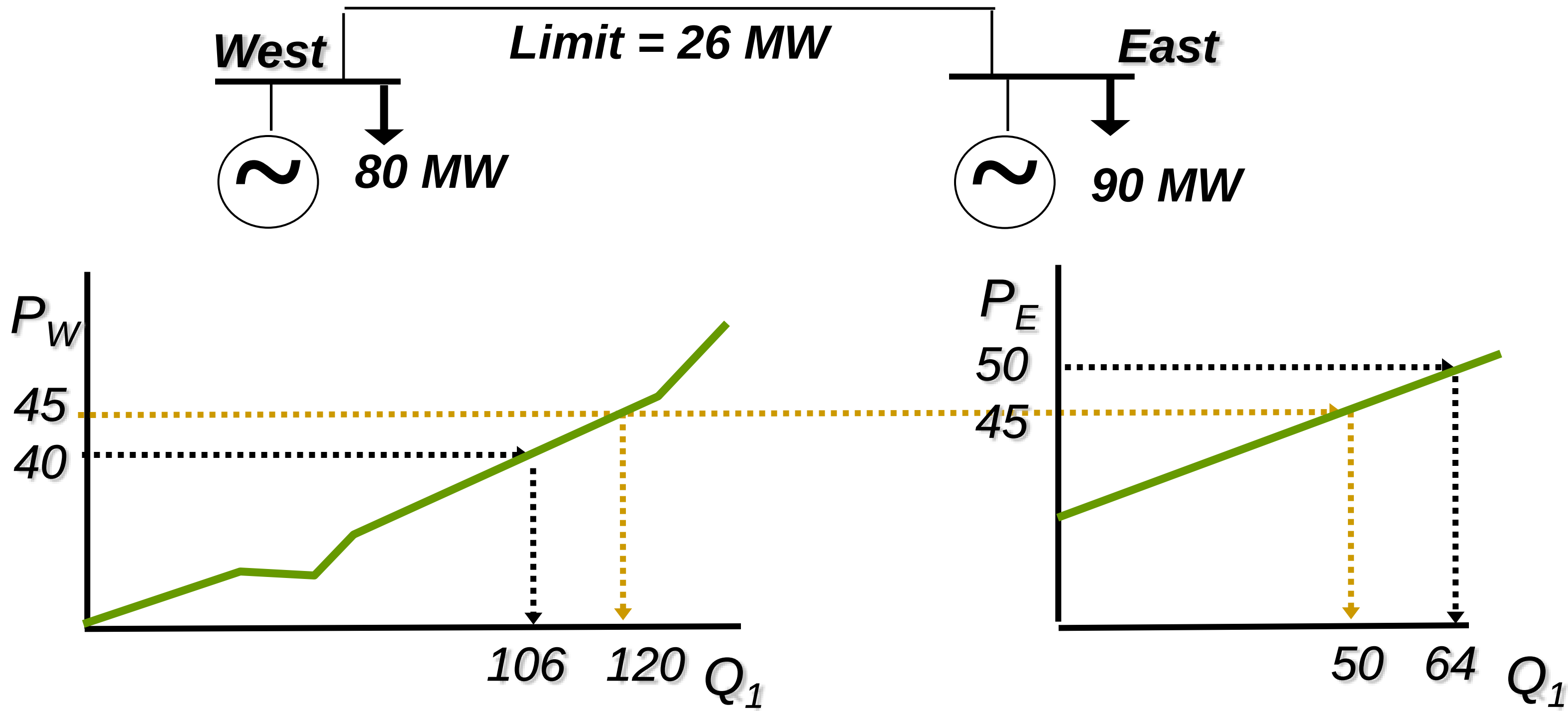
- ***Minimize S(Generator Fuel Cost)***

s.t.

- ***Energy balance (net supply = load at each node)***
- ***Generator limits (including dynamic limits such as ramp rates)***
- ***Transmission Constraints (AC model with voltage and thermal limits)***
- ***Reserve requirements***

(Cost curves and generator limits data provided as offers in real time auction every 15 minutes)

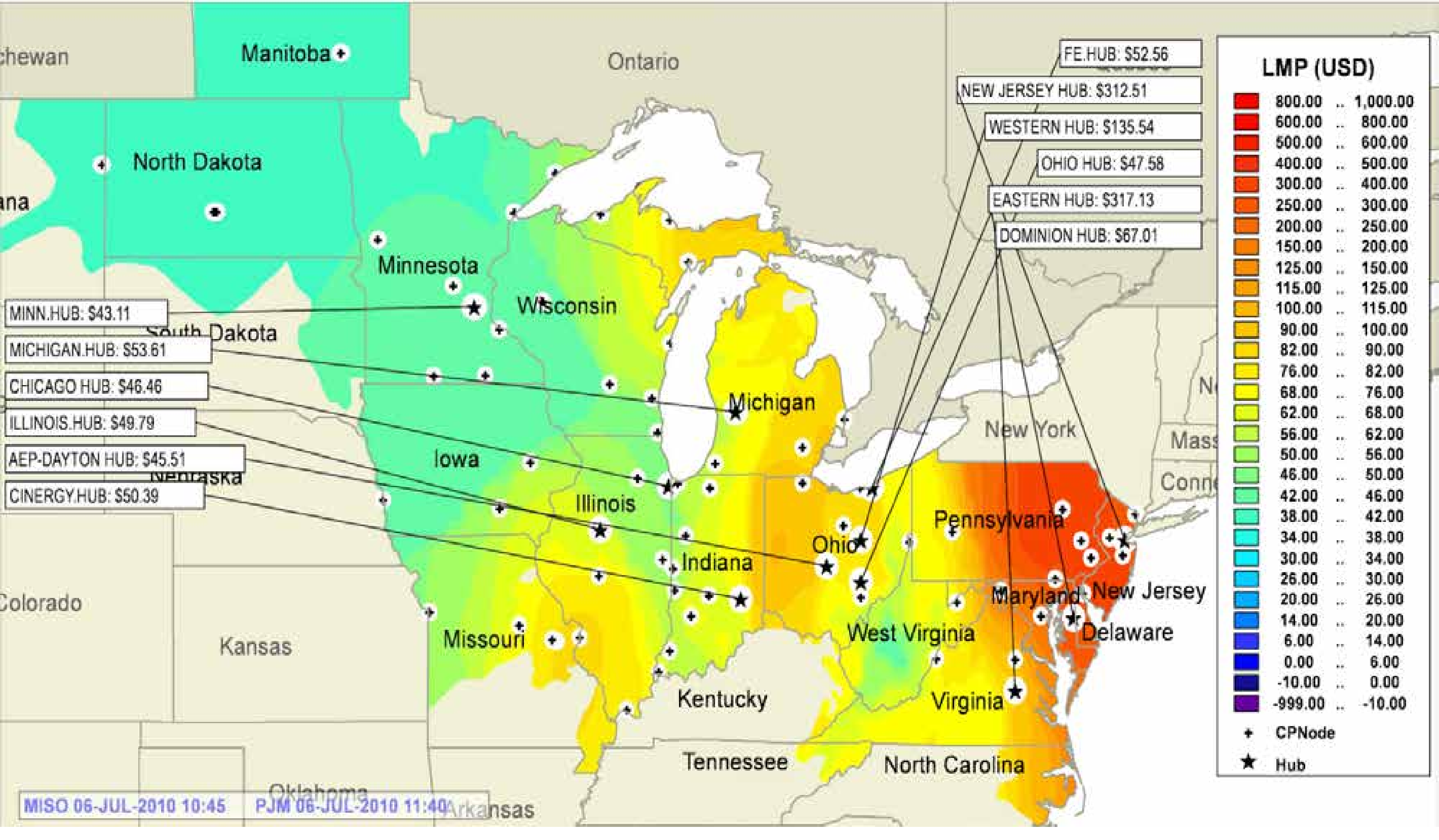
Congestion Management through LMP



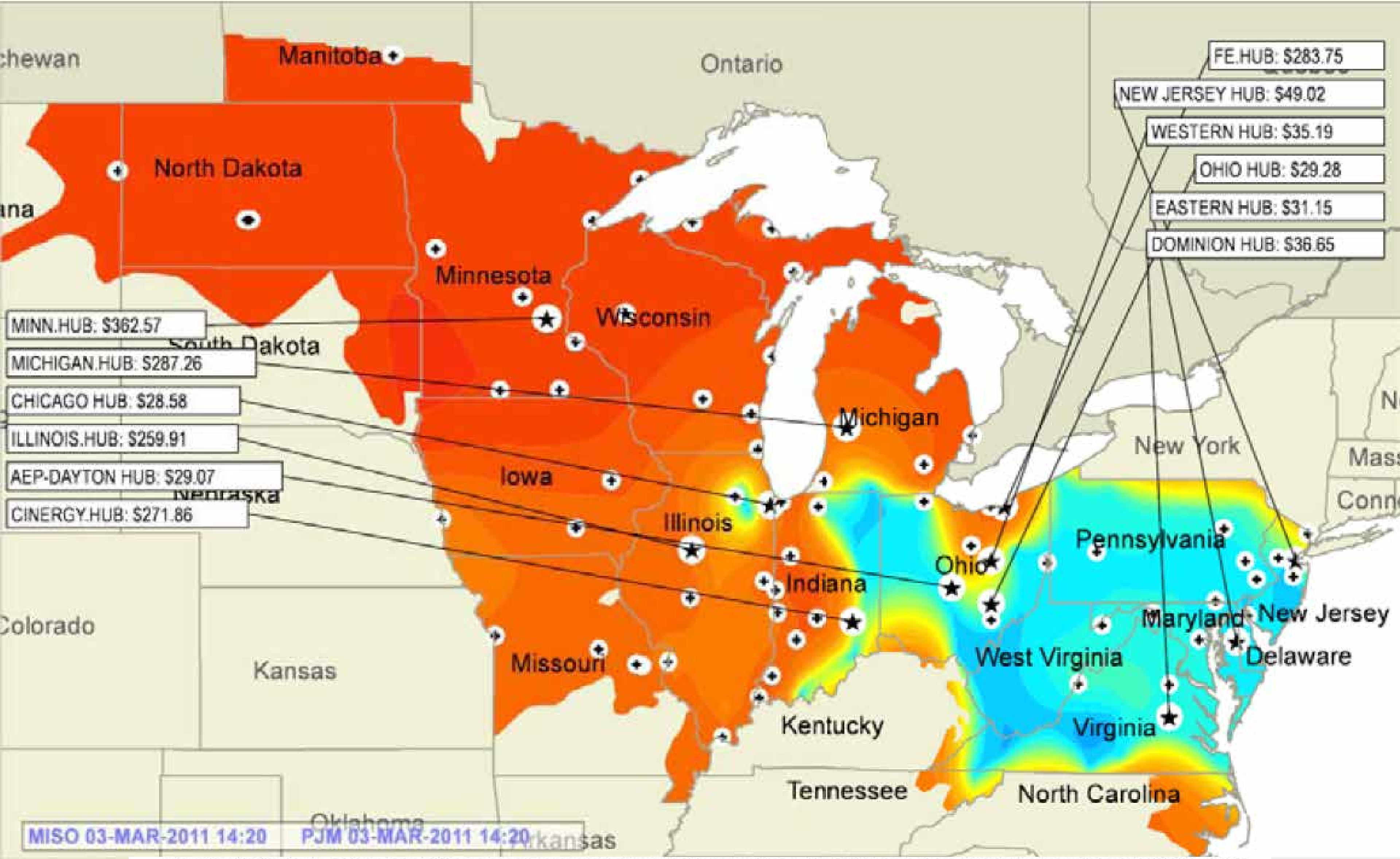
Key:

Prices/Supplies under 26 MW limit

Prices/Supplies with no transmission limit



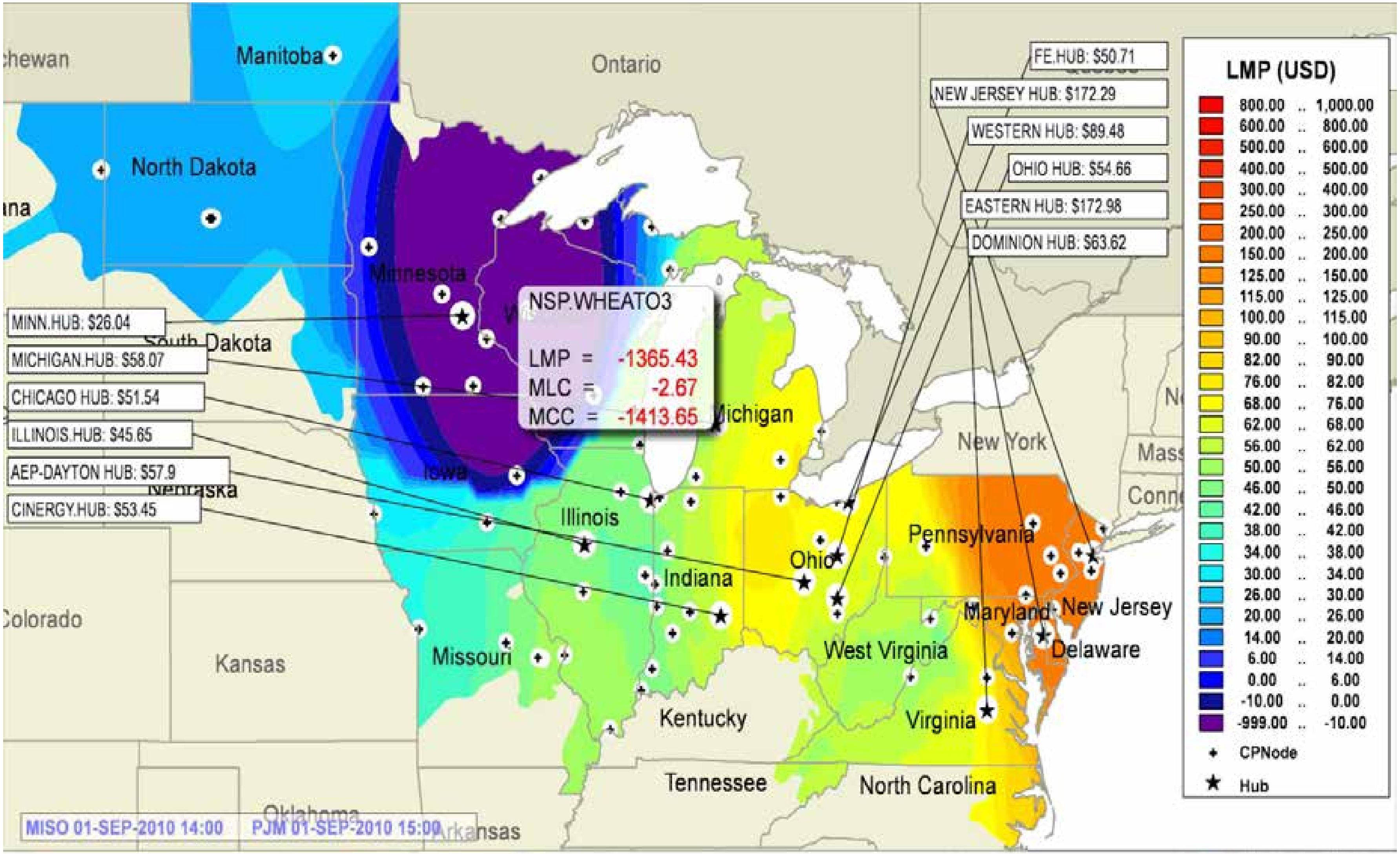
Manitoba
Ontario
North Dakota
Minnesota
Wisconsin
Michigan
South Dakota
Iowa
Nebraska
Illinois
Indiana
Ohio
Pennsylvania
New York
New Jersey
Maryland
Delaware
West Virginia
Virginia
Kentucky
Tennessee
North Carolina
Missouri
Kansas
Colorado
Oklahoma
Arkansas
FE.HUB: $52.56
NEW JERSEY HUB: $312.51
WESTERN HUB: $135.54
OHIO HUB: $47.58
EASTERN HUB: $317.13
DOMINION HUB: $67.01
MINN.HUB: $43.11
MICHIGAN.HUB: $53.61
CHICAGO HUB: $46.46
ILLINOIS.HUB: $49.79
AEP-DAYTON HUB: $45.51
CINERGY.HUB: $50.39
LMP (USD)
800.00 .. 1,000.00
600.00 .. 800.00
500.00 .. 600.00
400.00 .. 500.00
300.00 .. 400.00
250.00 .. 300.00
200.00 .. 250.00
150.00 .. 200.00
125.00 .. 150.00
115.00 .. 125.00
100.00 .. 115.00
90.00 .. 100.00
82.00 .. 90.00
76.00 .. 82.00
68.00 .. 76.00
62.00 .. 68.00
56.00 .. 62.00
50.00 .. 56.00
46.00 .. 50.00
42.00 .. 46.00
38.00 .. 42.00
34.00 .. 38.00
30.00 .. 34.00
26.00 .. 30.00
20.00 .. 26.00
14.00 .. 20.00
6.00 .. 14.00
0.00 .. 6.00
-10.00 .. 0.00
-999.00 .. -10.00
CPNode
Hub
MISO 06-JUL-2010 10:45
PJM 06-JUL-2010 11:40



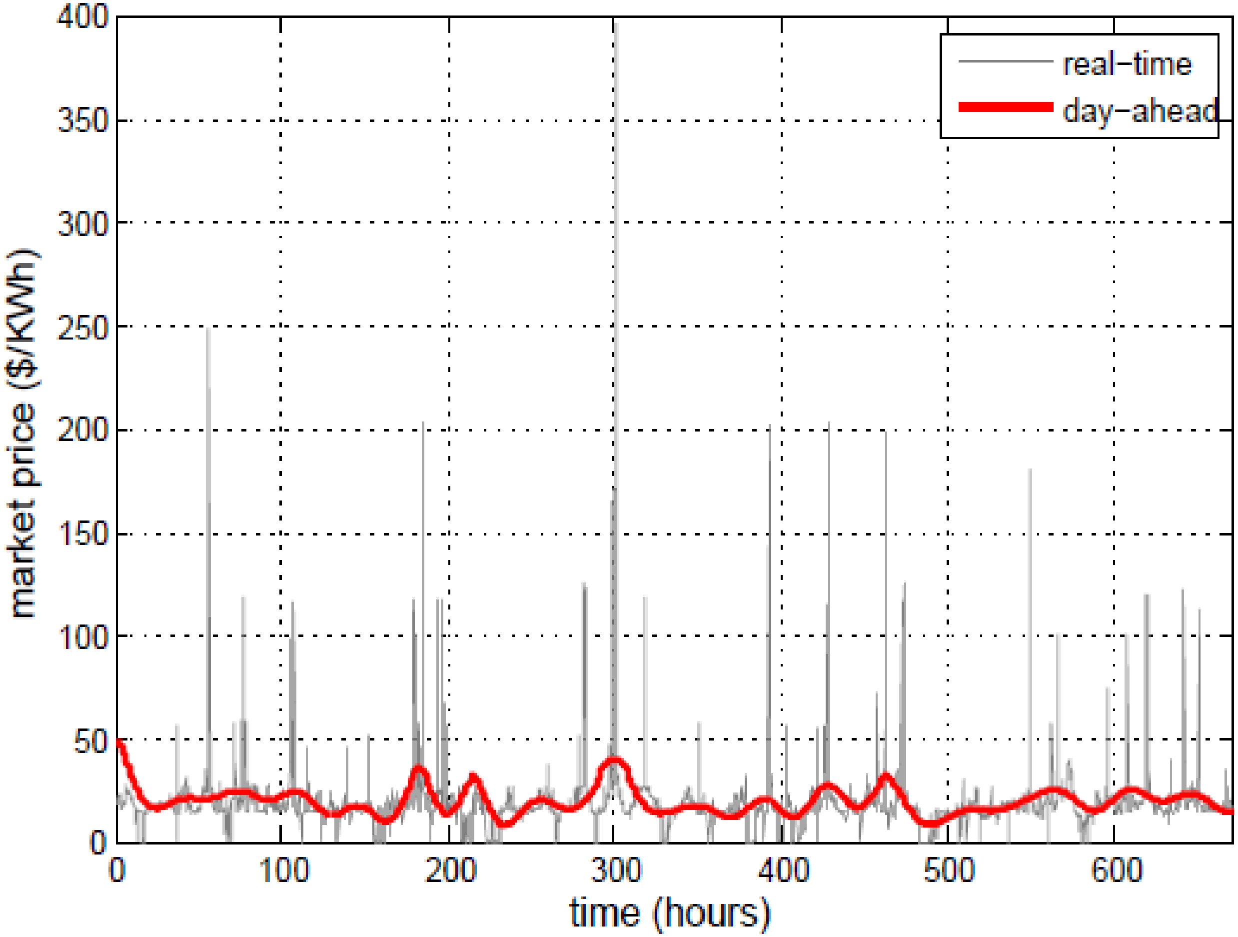
Midwest ISO Market data is based on Eastern Standard Time (EST) while PJM Market data is based on Eastern Prevailing Time.

MidwestISO Energizing the Heartland   pjm

Over-generation, congestion and no storage capability can lead to negative prices

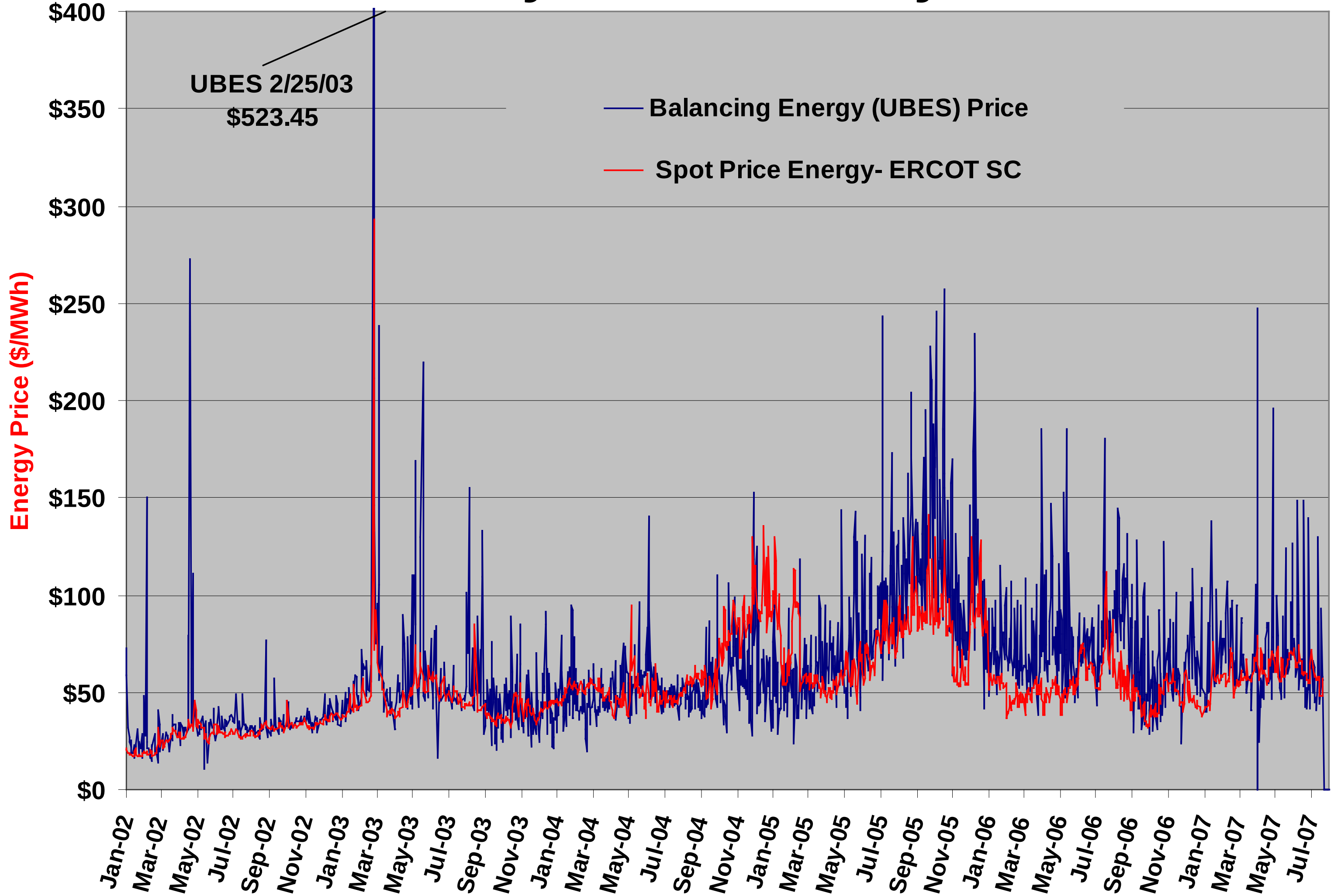


Example of DA-RT Price Spread



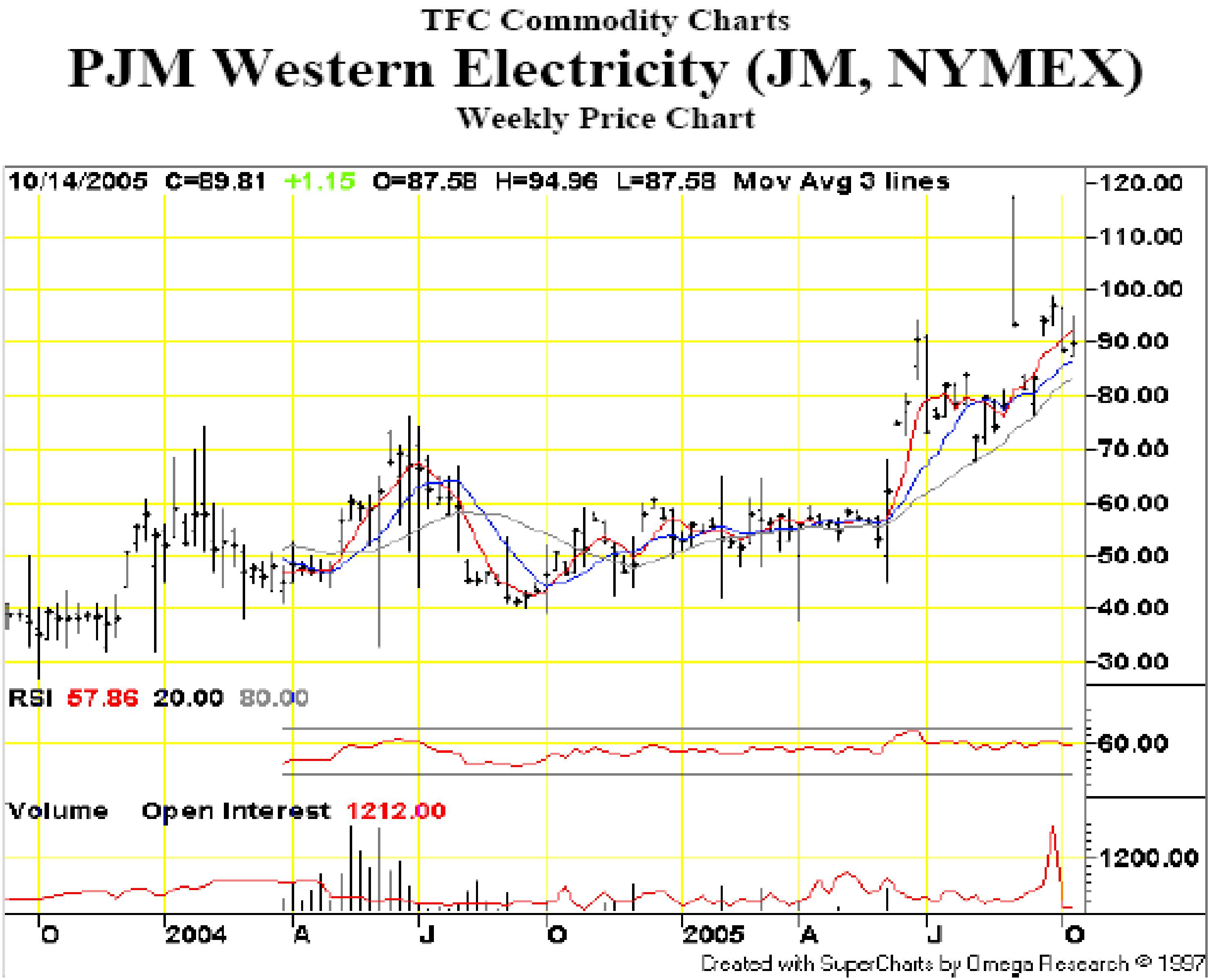
On-peak Balancing Market Prices at ERCOT

January 2002 thru July 2007



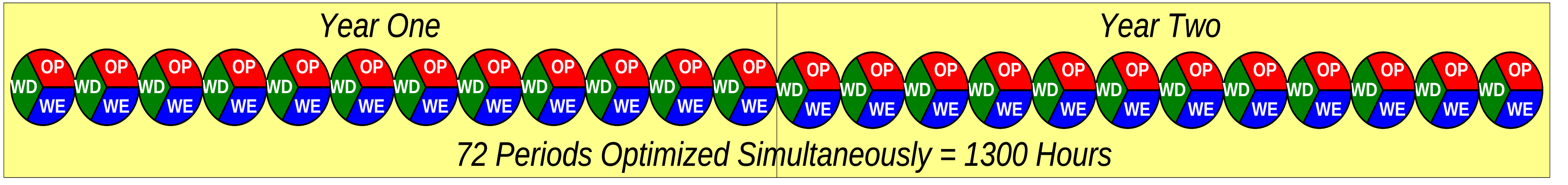
Temporal and Locational Hedging

Forward Contracts Mitigate Price Volatility and Market Power



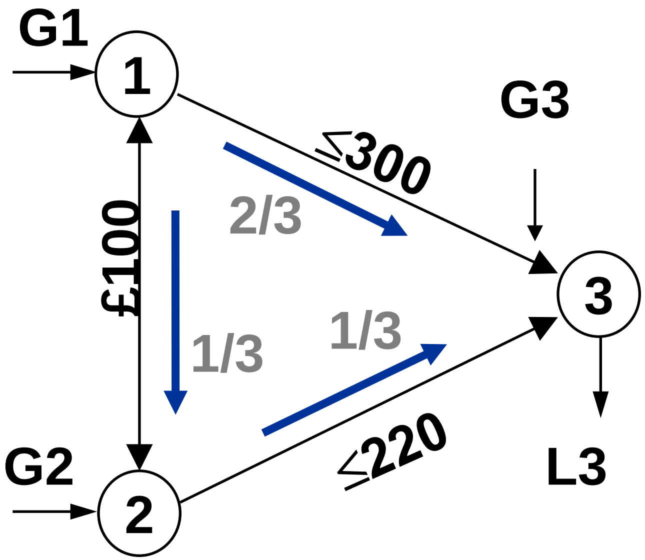
FTR Auction (ERCOT)

- 72 time slices
  (24 monthly blocks divided into 3 time blocks)
- Bids (and offers) can cover any subset of the 72 products



- Clearing mechanism maximizes auction revenue subject to simultaneous feasibility test (SFT) in every time slice
- SFT ensures that physical grid could support physical exercise of all outstanding FTRs

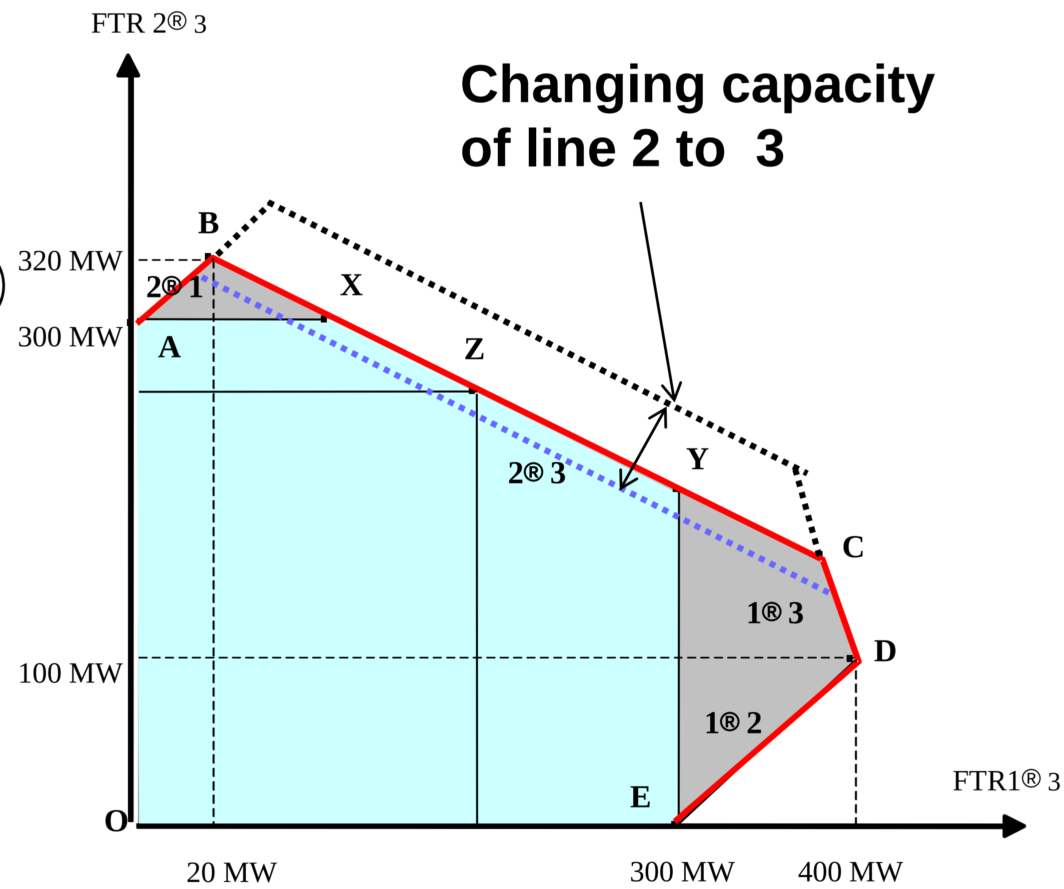
Simultaneous Feasibility Guarantees Revenue Adequacy (congestion revenues cover FTR settlements)



$$\tfrac{2}{3}G1+\tfrac{1}{3}G2 \text{ £ } 300$$

$$\tfrac{1}{3}G1+\tfrac{2}{3}G2 \text{ £ } 220$$

$$-100 \text{ £ } \tfrac{1}{3}(G1-G2) \text{ £ } 100$$



- **Two sided FTRs must stay within the outer nomogram**
- **One sided FTRs (options) must stay within the inner nomogram because we cannot rely on counterflows to alleviate congestion.**

LMP + FTRs Supports Renewables Penetration and Sharing of Transmission

$5/MWh
when available

LMP set by marginal
MW produced

Thermal unit owns FTRs

LMP=$60/MWh

$30/MWh

Without wind, Thermal Gen earns 60-30=$30 per MWh exported over transmission lines and its FTRs offset congestion charges.
With wind, Thermal Gen has incentive to let wind maximize output and set LMP to $5/MWh and collect 60-5=$55 per MWh exported over the transmission line for its unused FTRs. Wind can be subsidized by “use it or loose it” FTR awards to offset congestion cost

Ancillary Services

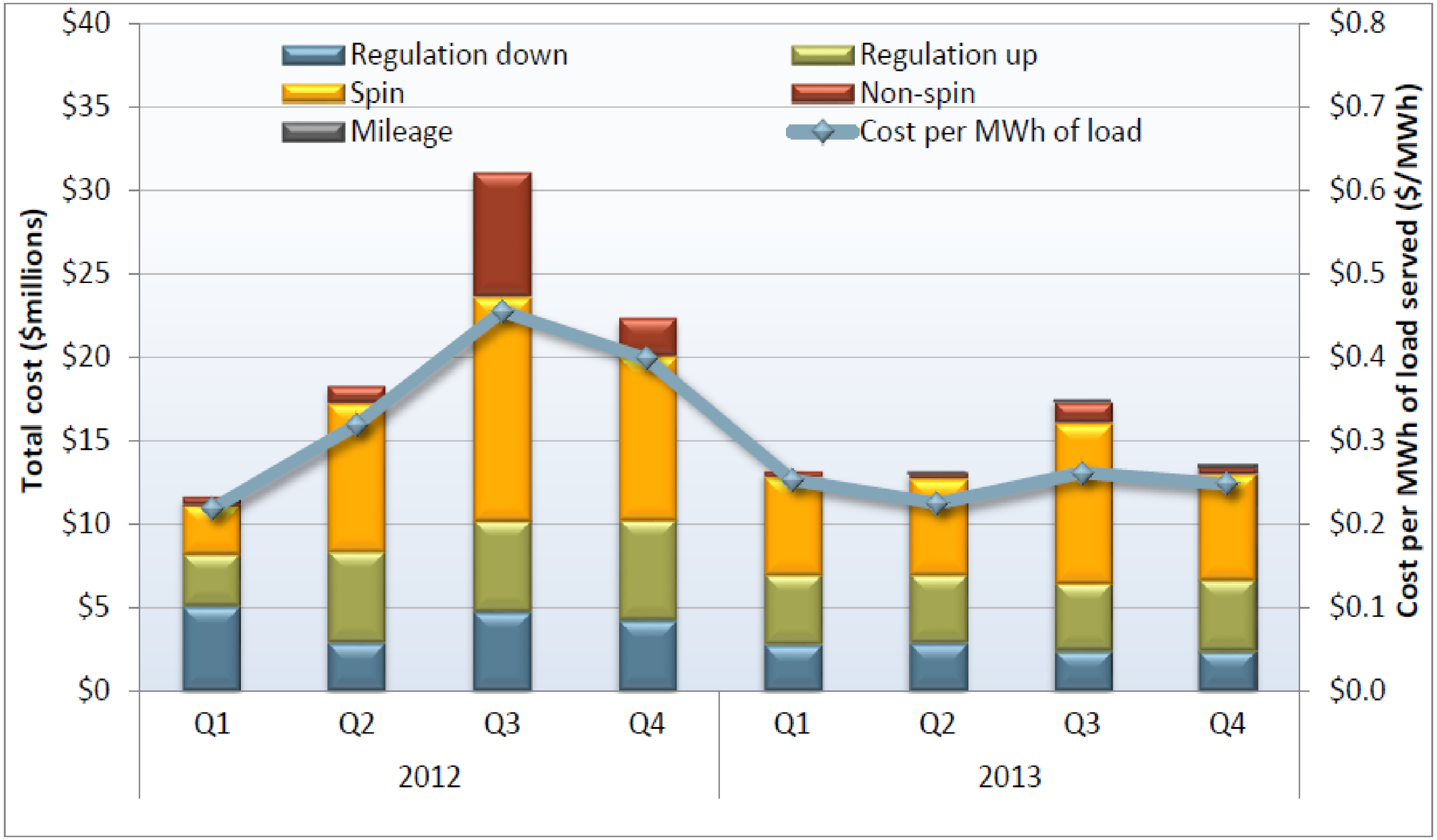
- Automatic Generation Control (AGC) – Regulation (Up/Down)
  - Payment for capacity and performance payment for "mileage" (FERC Order 755)
- Flexible Ramping
  - Opportunity cost payment based on energy bid
- Reserves with varying different response time
  - Spinning (synchronized) Reserves - Spin
  - Non-spinning (non-synchronized) Reserves
  - Replacement Reserves

  Payment for capacity
- Voltage Support
- Black Start Capability

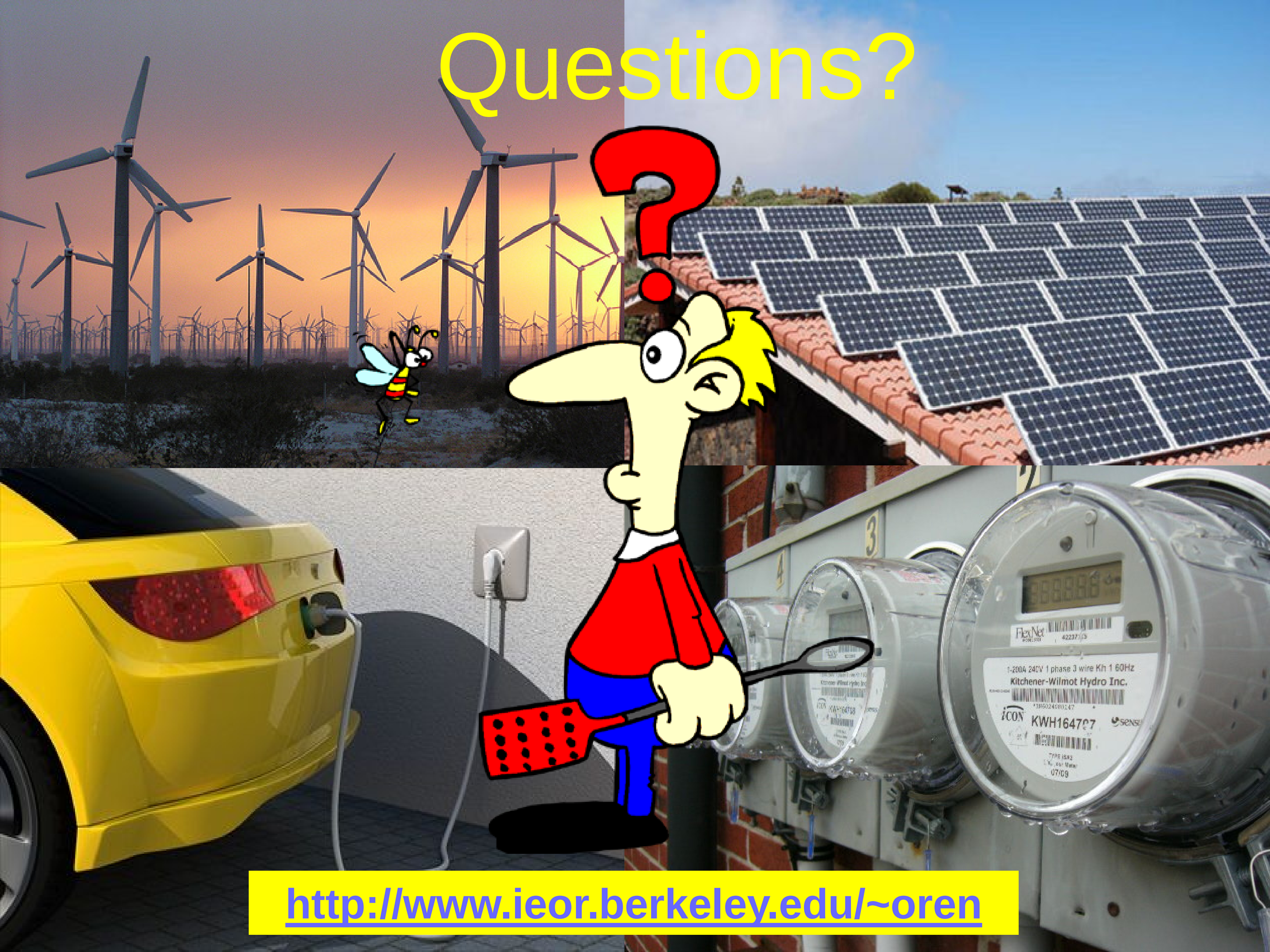
  Payment per contract

Cost Components (California)

Figure 6.7 Ancillary service cost by product



Questions?



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