Demand Response Opportunities Facilitated by Smart Grid Technologies in PJM

Optimized Distribution Systems for High Penetration of Renewables Smart Grid Workshop

TomKat Center for Sustainable Energy
Stanford University

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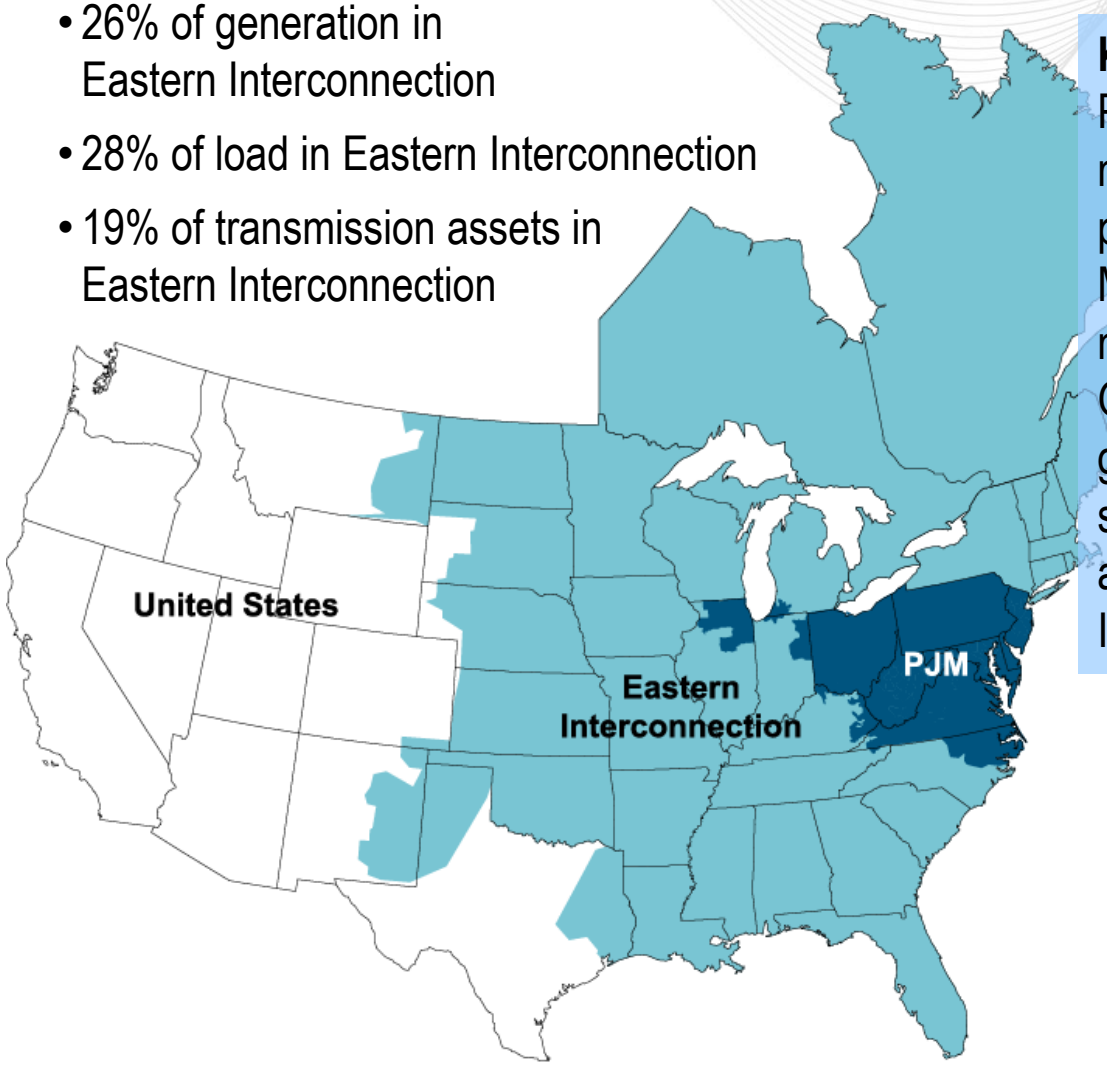
PJM Interconnection

PJM as Part of the Eastern Interconnection

- 26% of generation in Eastern Interconnection
- 28% of load in Eastern Interconnection
- 19% of transmission assets in Eastern Interconnection



KEY STATISTICS

PJM member companies	750+
millions of people served	60
peak load in megawatts	163,848
MWs of generating capacity	185,600
miles of transmission lines	65,441
GWh of annual energy	832,331
generation sources	1,365
square miles of territory	214,000
area served	13 states + DC
Internal/external tie lines	142

21% of U.S. GDP produced in PJM

As of 1/4/2012

Demand Response—
From Demand-side to Supply-side and Back

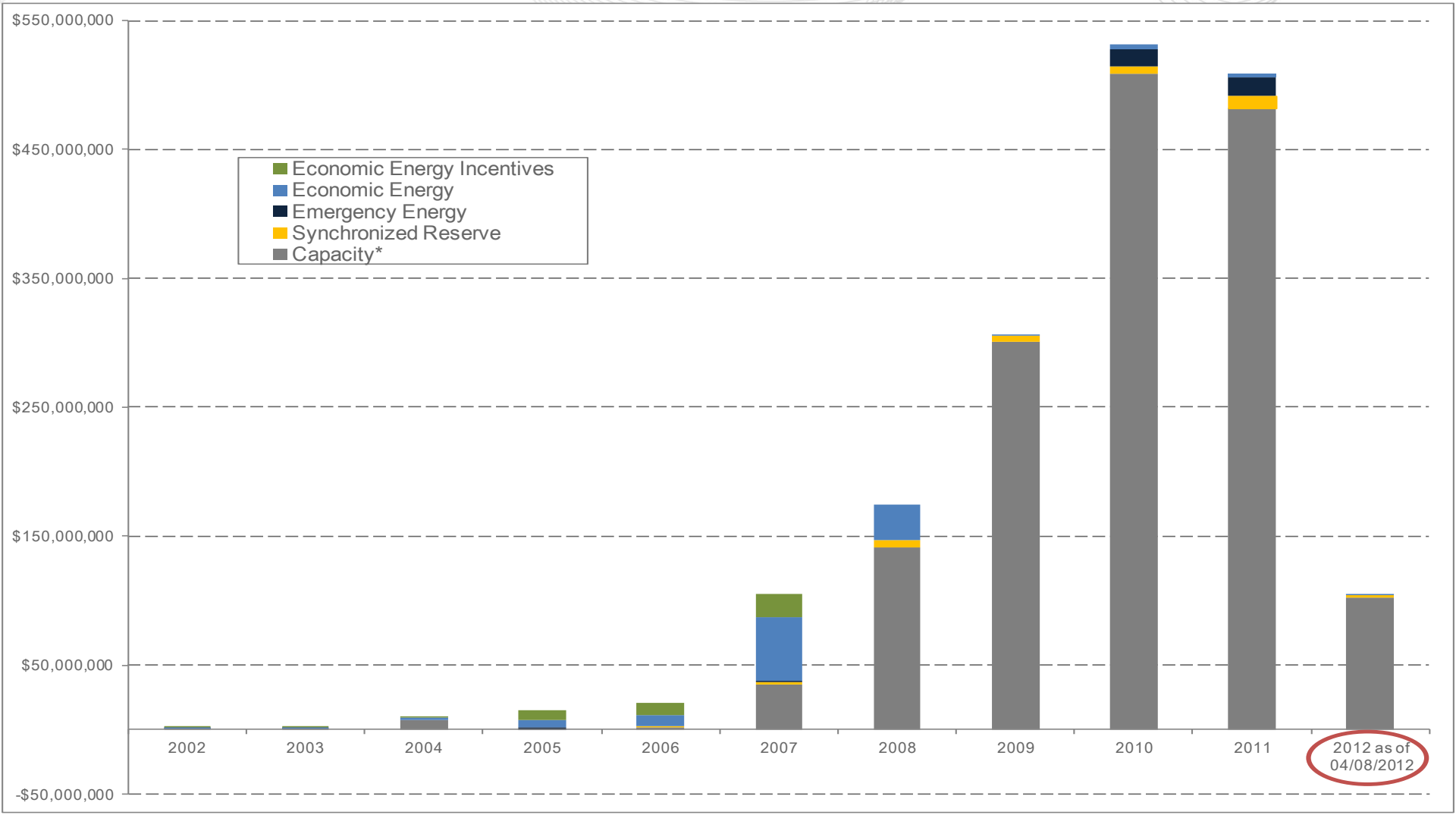
	Load Serving Entity (LSE) Peak Shaving ---The Original Demand-side DR	PJM Demand Response (DR) Resource ---Treating DR like a Supply Resource	PJM PRD---The Ultimate Demand-side DR
Characteristics	LSE Manages Peak Load Contribution (PLC) outside of any PJM program	Offered as Supply Resource in Capacity & Energy Markets	Reduces Load Forecast (and therefore Reliability Requirements) in Capacity Market
Performance Requirements	LSE proactively manages load, especially during expected 5 Coincident Peak (CP) days.	Different Requirements: •Unlimited •Summer Only Unlimited •Limited	PRD Provider implements dynamic prices that produce predictable reduction in demand during emergency conditions
Financial Impact	Reduce Peak Load Contribution (PLC) and purchase less capacity in next delivery year.	Receive revenue based on RPM results. Capacity Resource deficiency + event or test deficiency penalty	Reduces net capacity obligation charges during delivery year. Penalties if load is not reduced
Metering Requirements	No explicit requirement but if competitive jurisdiction interval meter may be required to see full impact to customer.	Interval metering required unless part of 500 MW pilot or direct load control program One way communication in operations and markets.	Interval Metering Supervisory Control Implicit or Explicit two-way communication in markets and operations

21st Century Grid—Technology Catches Up with Economic Theory and System Operation

Electromechanical/Analog	Digital
One-way communications (if any)	Two-way communications
Built for centralized generation	Accommodates distributed generation
Radial topology	Network topology
Few sensors	Monitors and sensors throughout
“Blind”	Self-monitoring
Manual restoration	Semi-automated restoration and eventually, self-healing
Prone to failures and blackouts	Adaptive protection and islanding
Check equipment manually	Check equipment remotely
Emergency decisions by committee and phone	Decision support systems, predictive reliability
Limited control over power flows	Pervasive control systems
Limited price information	Full price information
Few consumer choices	Many consumer choices

Wholesale Competitive Electricity Markets Provide Opportunities for Demand Response Across Multiple Markets

Value of Demand Response
Estimated Revenue by Service



*Capacity revenue prior RPM implementation on 6/1/07 estimated based on average daily ALM capacity credits and weighted average daily PJM capacity market clearing price.

Monetizing the Capacity Innovative Technologies: Reliability Pricing Model (RPM) Capacity Market

- RPM
  - 3-year forward capacity market designed to work in concert with energy market outcomes
    - Up to three additional incremental auctions to transact capacity
  - Supply offers from generation resources are capped at avoidable costs (fixed costs including costs of needed investment) less expected net energy market revenues
    - Offers can include the costs of environmental retrofits
    - Demand resources and energy efficiency are not subject to offer caps
  - Capacity beyond the installed reserve margin is purchased when cost-effective to do so
    - On an RTO-wide basis today PJM has more capacity resources than needed to meet the installed reserve margin
  - ***Value of capacity is transparent for all to see!***

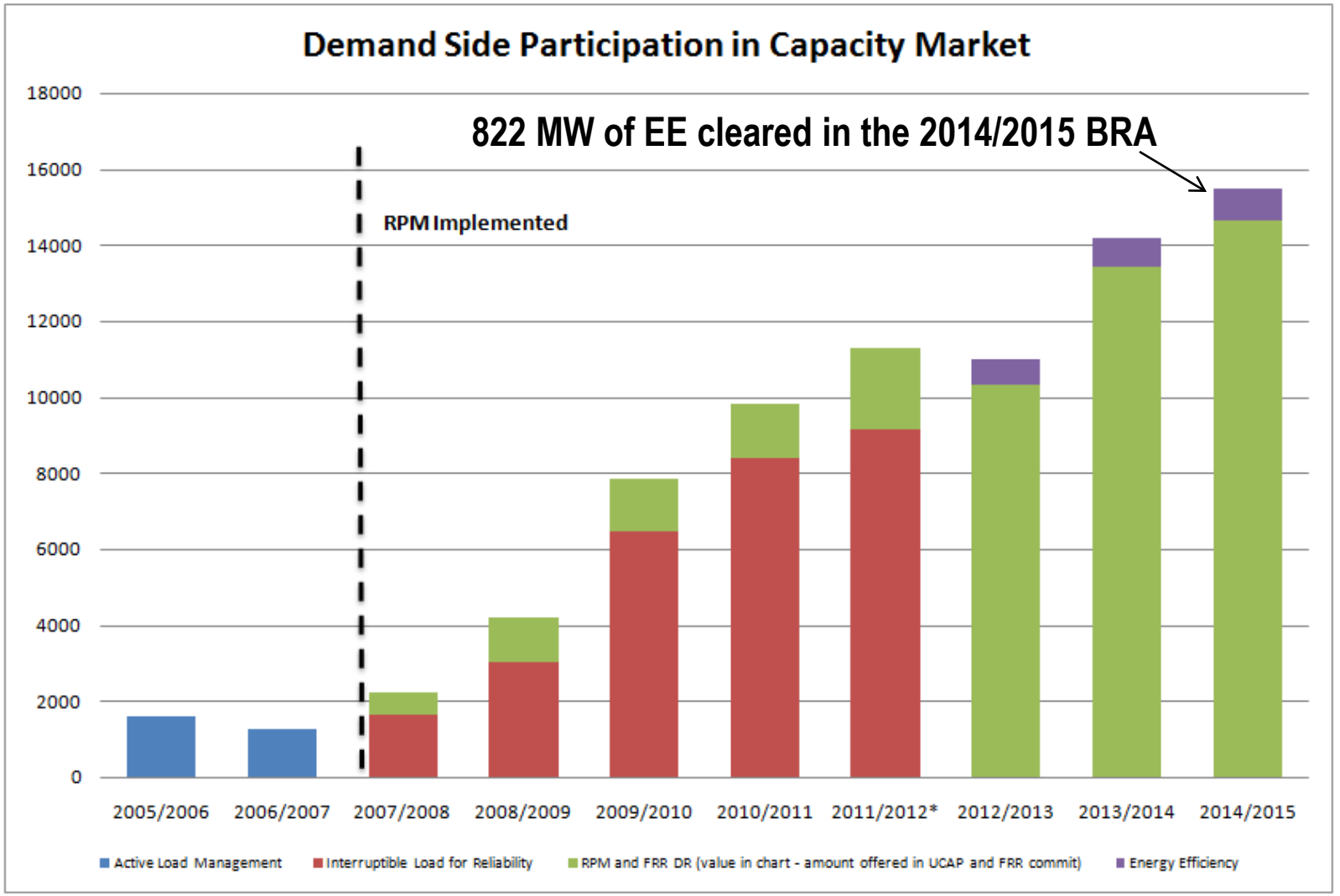
Recent RPM Capacity Prices in PJM ($/MW-day of Unforced Capacity)

Delivery Year	MAAC	Rest of PJM RTO
2011/2012	$110.00	$110.00
2012/2013	$133.37	$16.46
2013/2014	$226.15	$27.73
2014/2015	$136.50	$125.99

Net Cost of New Entry for 2014/2015 in MAAC $241.91/MW-day UCAP
Net Cost of New Entry for 2014/2015 in RTO $342.23/MW-day UCAP
Installed Reserve Margin in the RTO of over 19% for 2014/2015…in excess of the 15.3% target

RPM prices and the Net Cost of New Entry indicate new entry of generation capacity resources has not been needed, except possibly in the eastern part of PJM

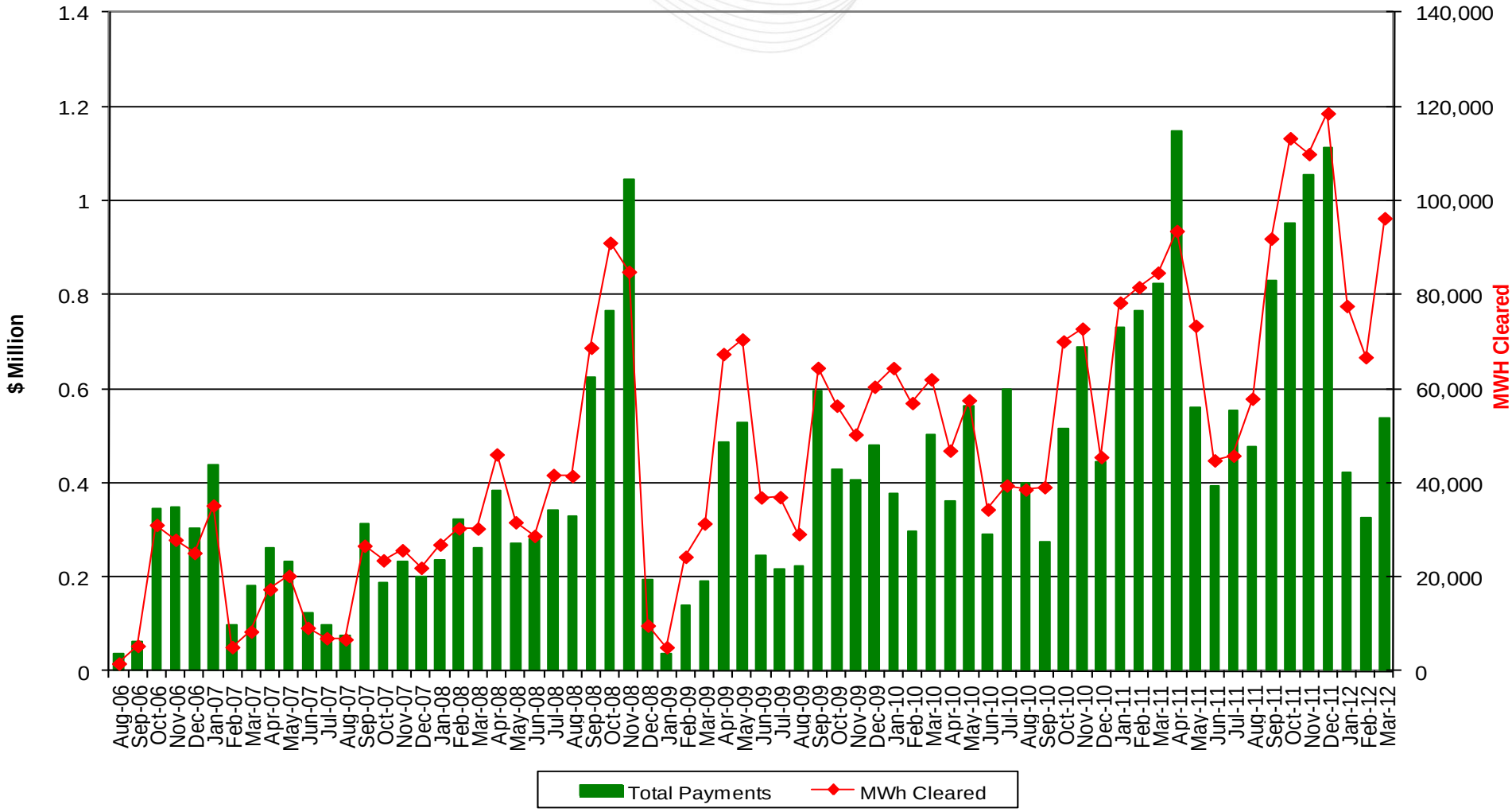
Offers of Demand Resources and Energy Efficiency as Capacity in PJM by Delivery Year



Demand Response and Energy Efficiency in PJM's Markets

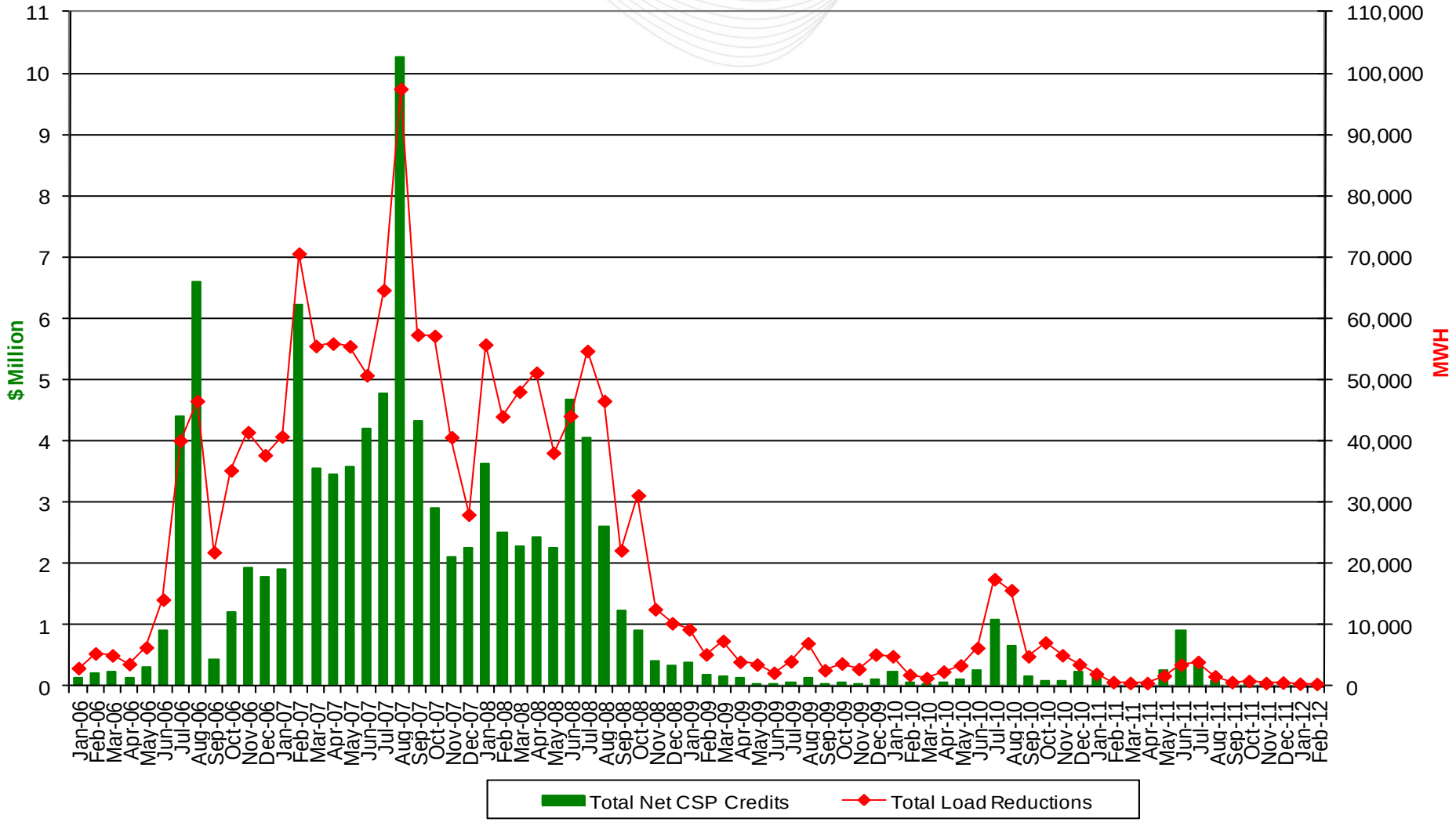
- RPM Capacity Market monetizes the value of DR and EE
  - Value in the Energy Market is in the form of avoided energy costs
- If EE follows DR in its evolution, then much more capacity will be made available in subsequent auctions
- Other environmental policies and market trends may increase the value of capacity, including that from energy efficiency
  - EPA rulemakings and state policies
  - Renewable portfolio standards
  - Natural gas prices

DSR Participation in PJM Synchronized Reserve Markets

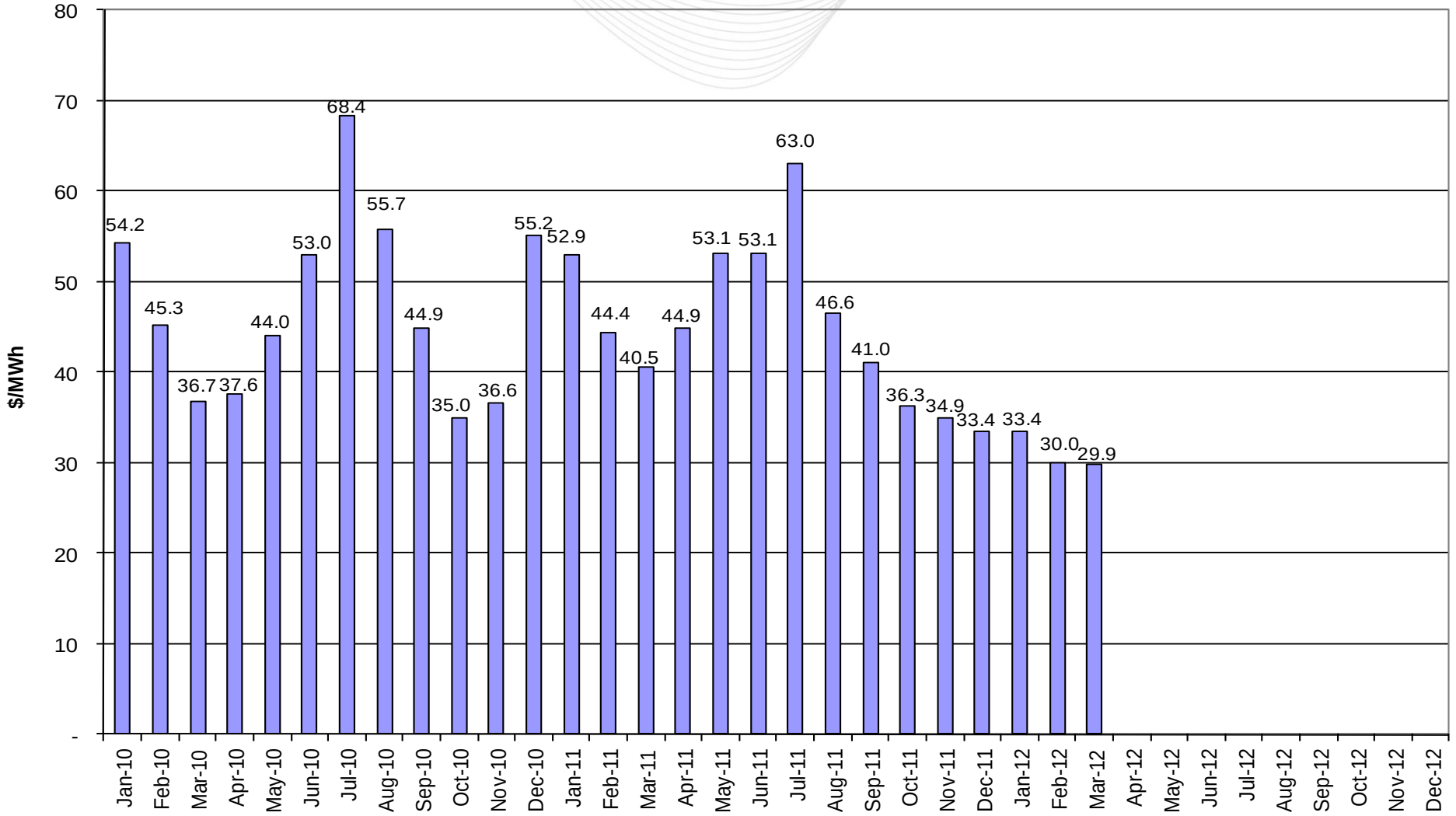


PJM Economic Demand Response Activity

*Data for last few months are subject to significant change due to the settlement window.

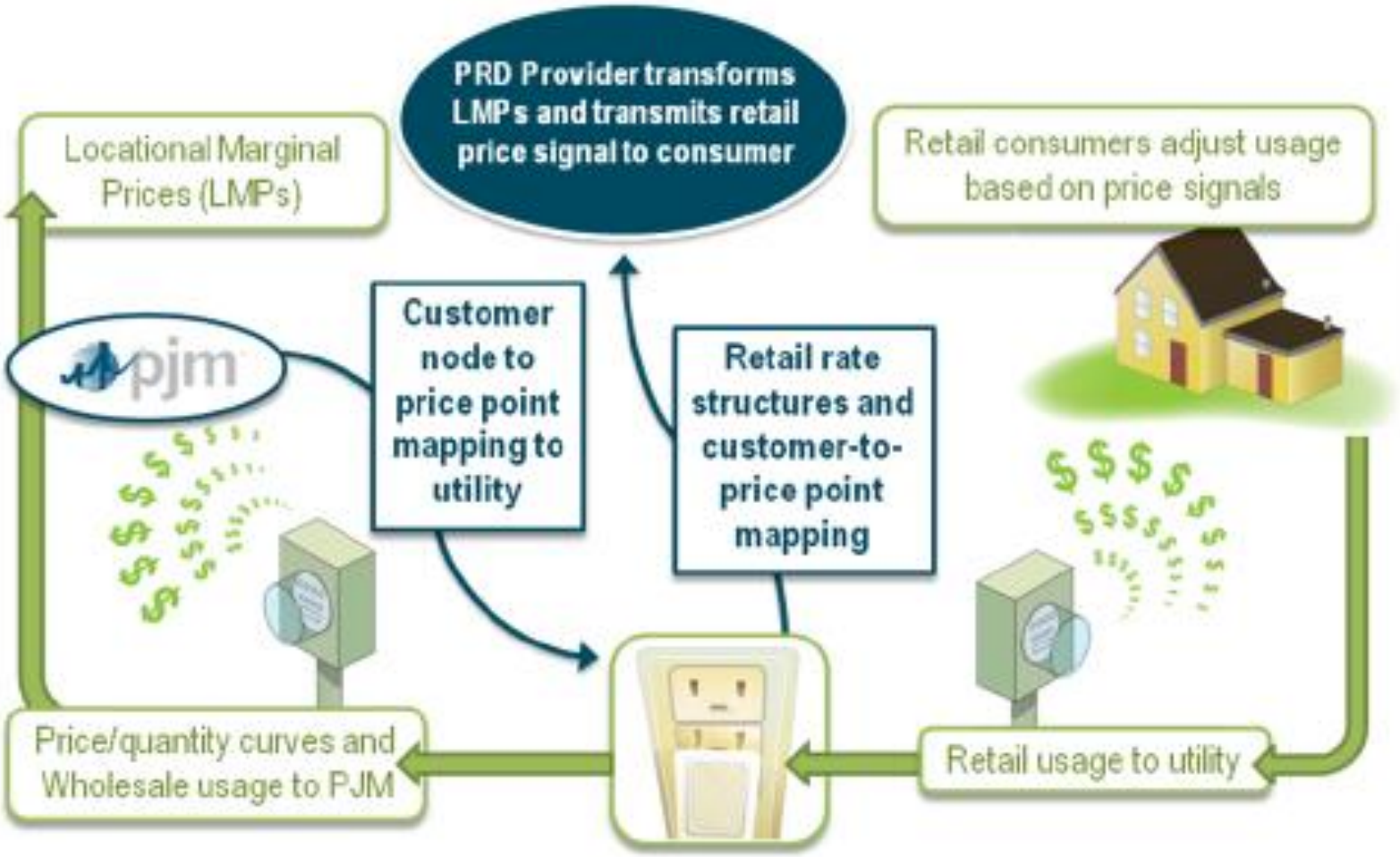


PJM Load-Weighted Average LMP 2010-2012

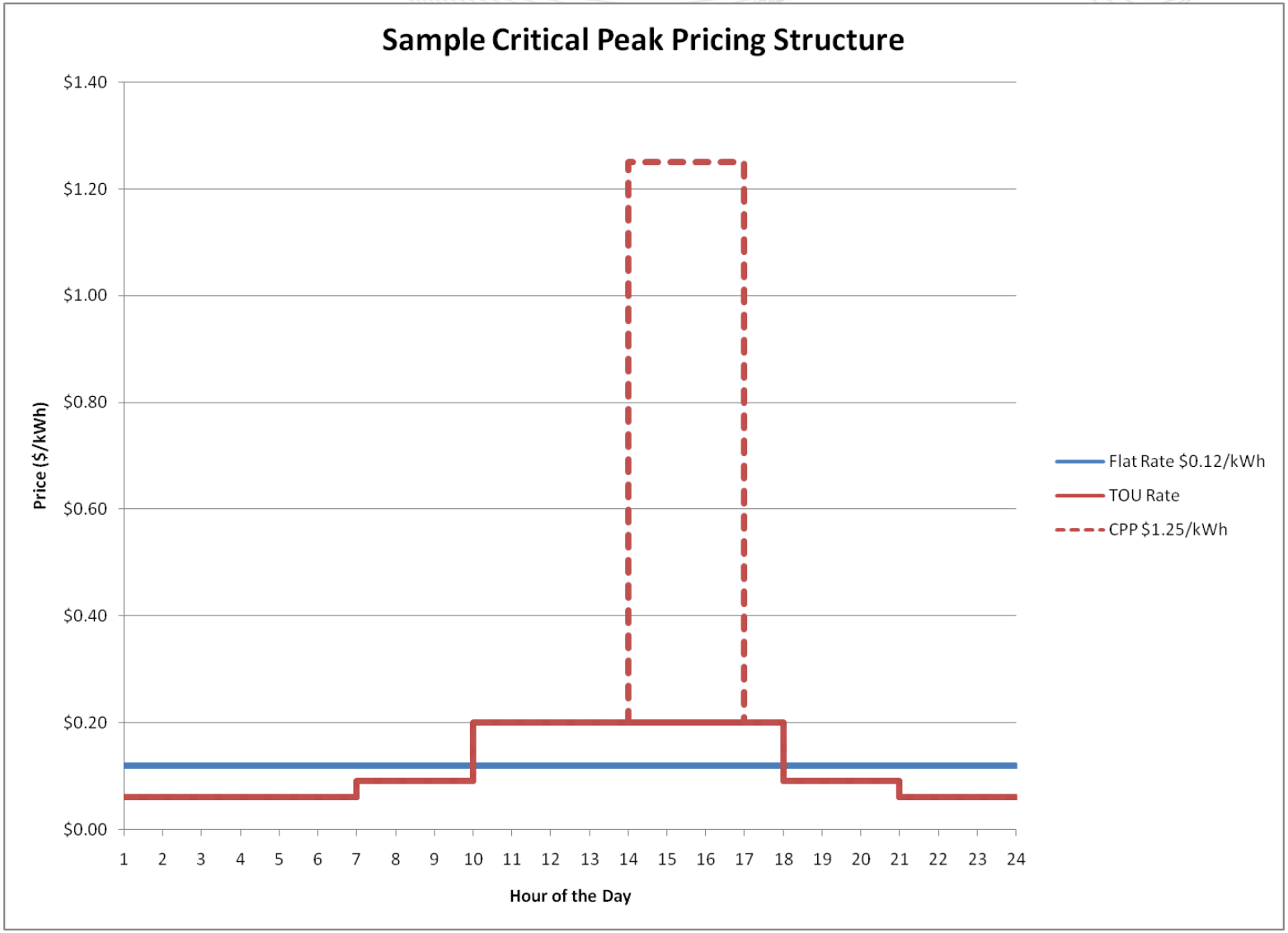


Wholesale Competitive Electricity Markets as the Link to the Future of Demand Response… Price Responsive Demand

Price Responsive Demand…the Next Step



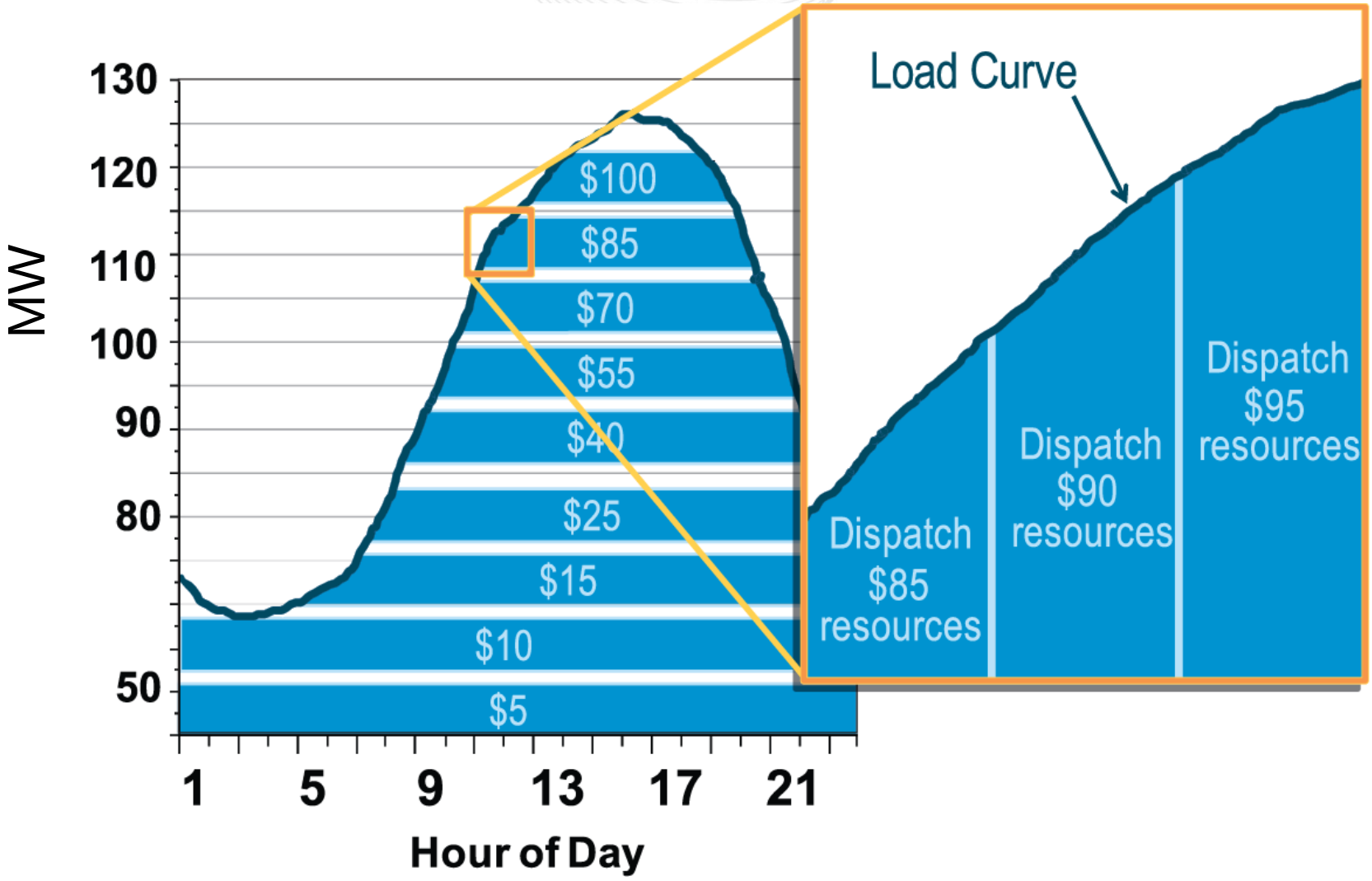
Dynamic Retail Rates Linked to Wholesale Prices
Critical Peak Pricing



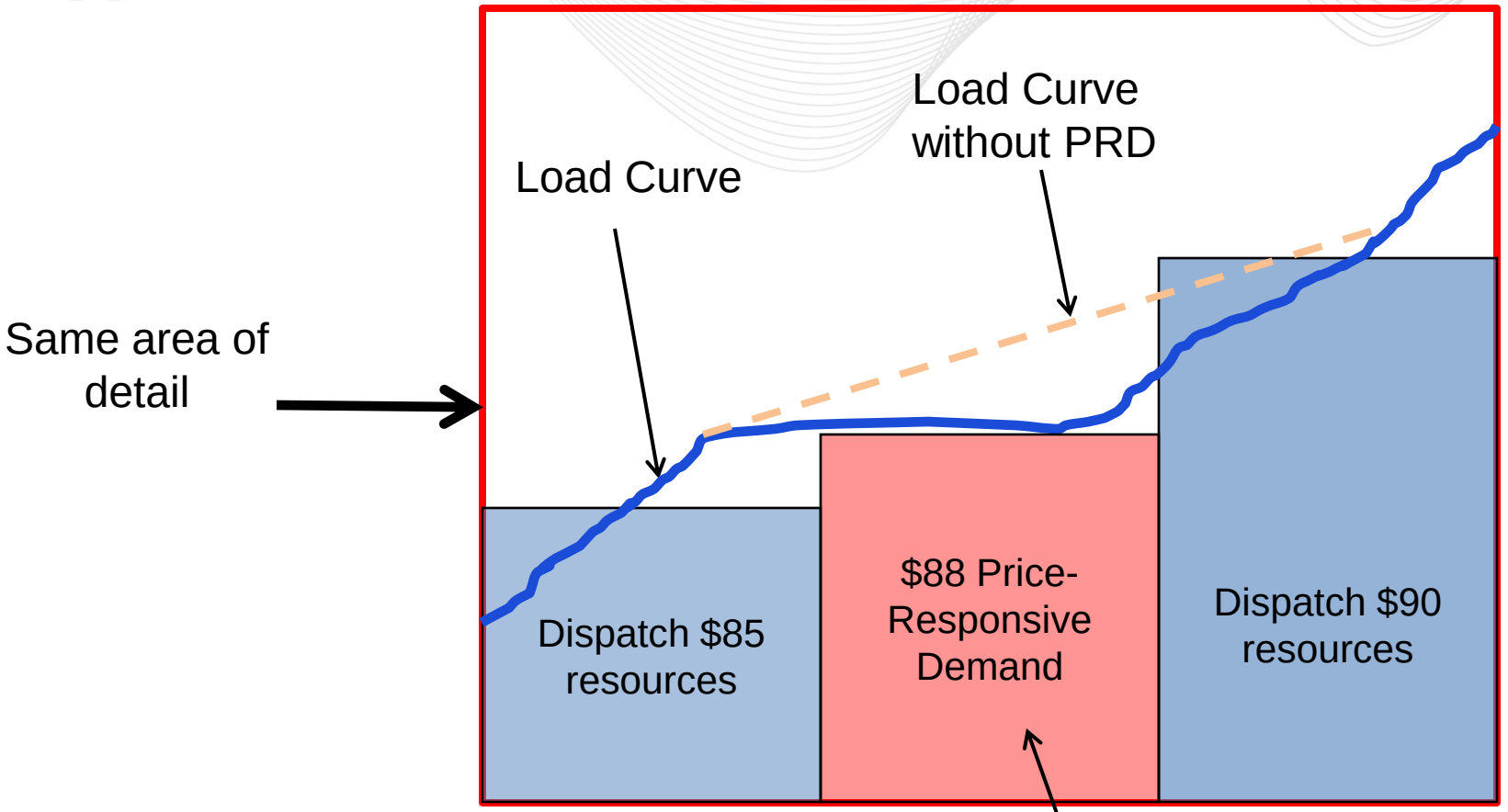
Example of Linking Critical Peak Pricing to Real-time LMP for PRD

- Critical Peak Pricing
  - The critical peak retail price is $1.25/kWh ($1250/MWh). In all other hours the retail rate is flat at $0.12/kWh.
  - The critical peak price is triggered when Real-time LMP hits $500/MWh or greater. Otherwise customer face the flat rate. (Note that the trigger price does not have to equal the CPP rate!)
  - LSE knows relationship between consumption levels and the CPP for a given set of other conditions, weather in particular
- For the purposes of constructing a PRD curve used in a particular hour in the wholesale market:
  - At prices below $500/MWh, the LSE will consume 2500 MWh and at prices at or above $500/MWh will only consume 1600 MWh

Today's Economic Dispatch of Supply Resources



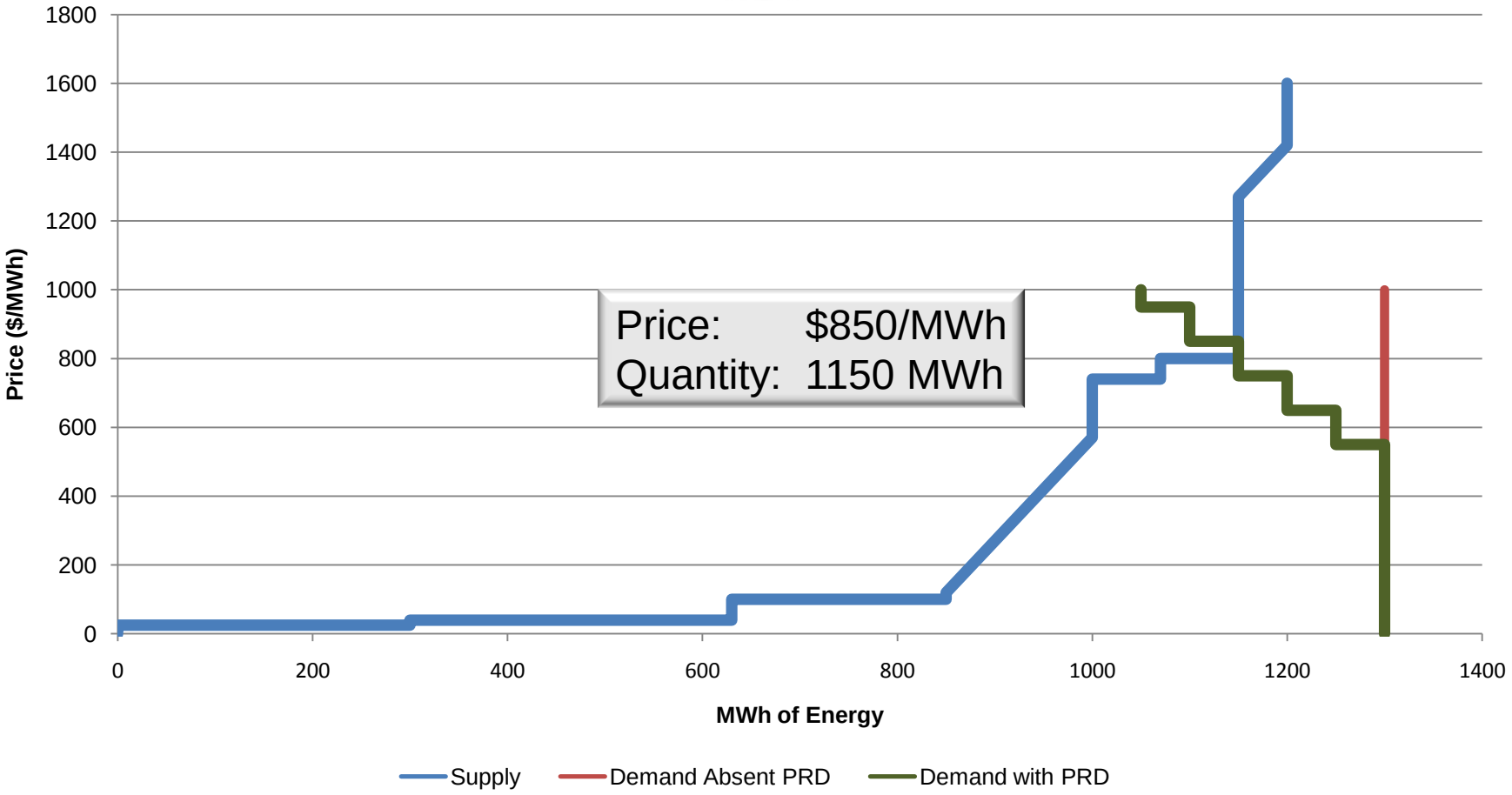
Dispatch Incorporating Price Responsive Demand



No dispatch of additional resources due to demand response at indicated price level

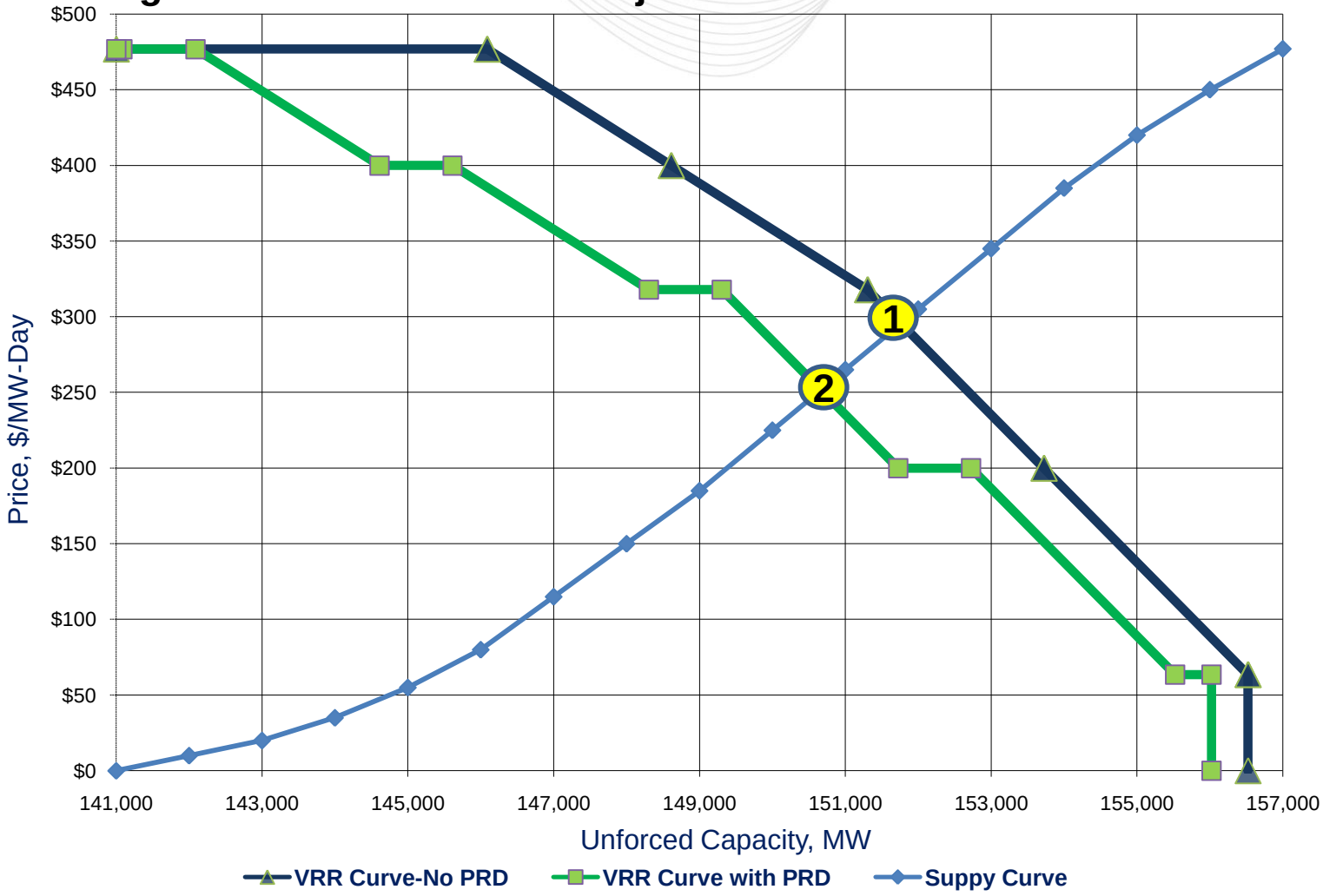
PRD Provides Real-time Reliability Value at System Peaks

PRD Can Prevent the Involuntary Shedding of Load and Mitigate Price Levels at Peak

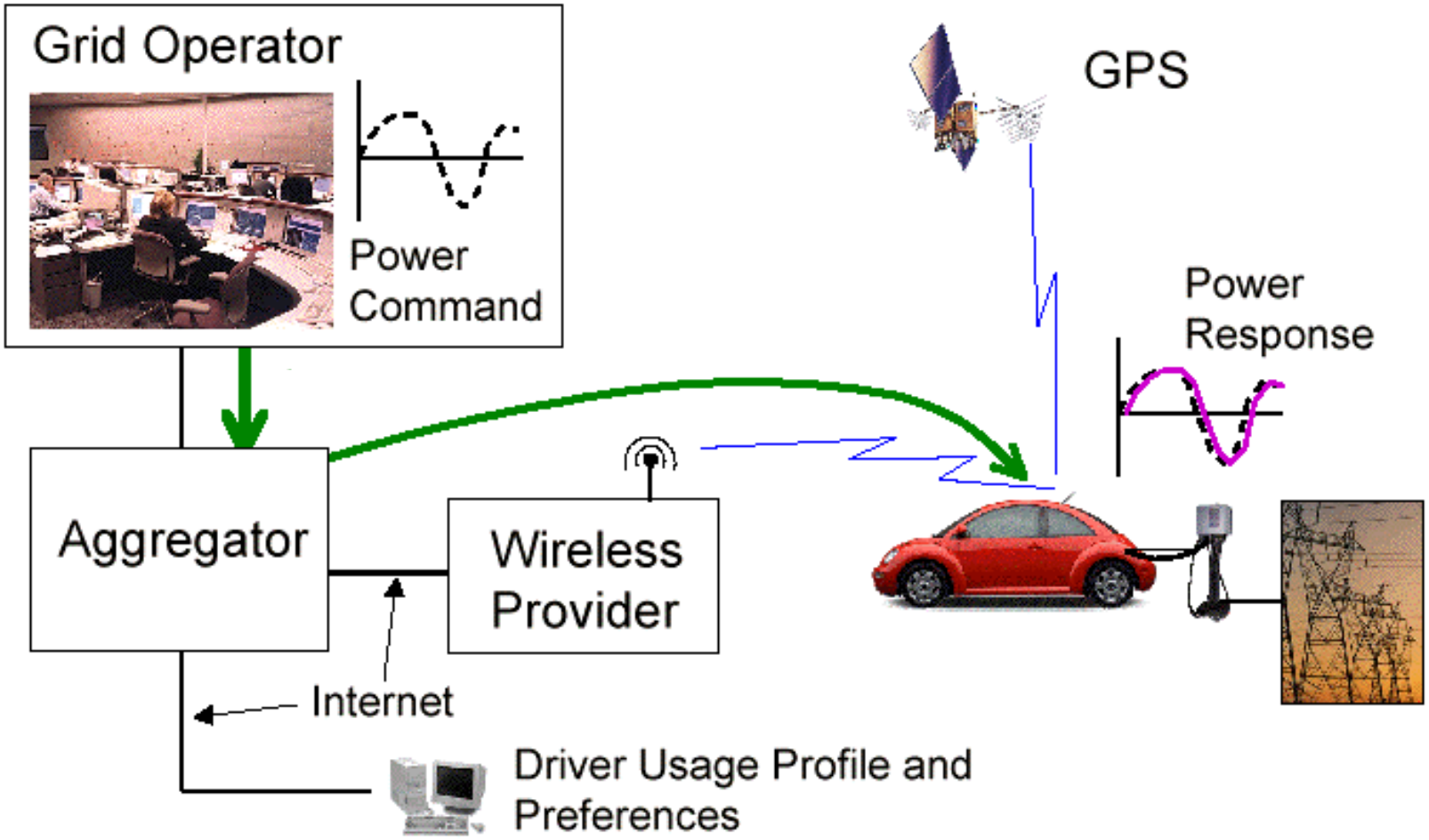


Initial and PRD-Adjusted VRR (Demand) Curve for Capacity

Figure 1: Initial and PRD-Adjusted VRR Curve for RTO



The Mid-Atlantic Grid-Interactive Car (MAGIC) Consortium
Vehicle to Grid (V2G) Concept



Exploiting the Demand-side to Provide Regulation and Frequency Response---FERC Order 755

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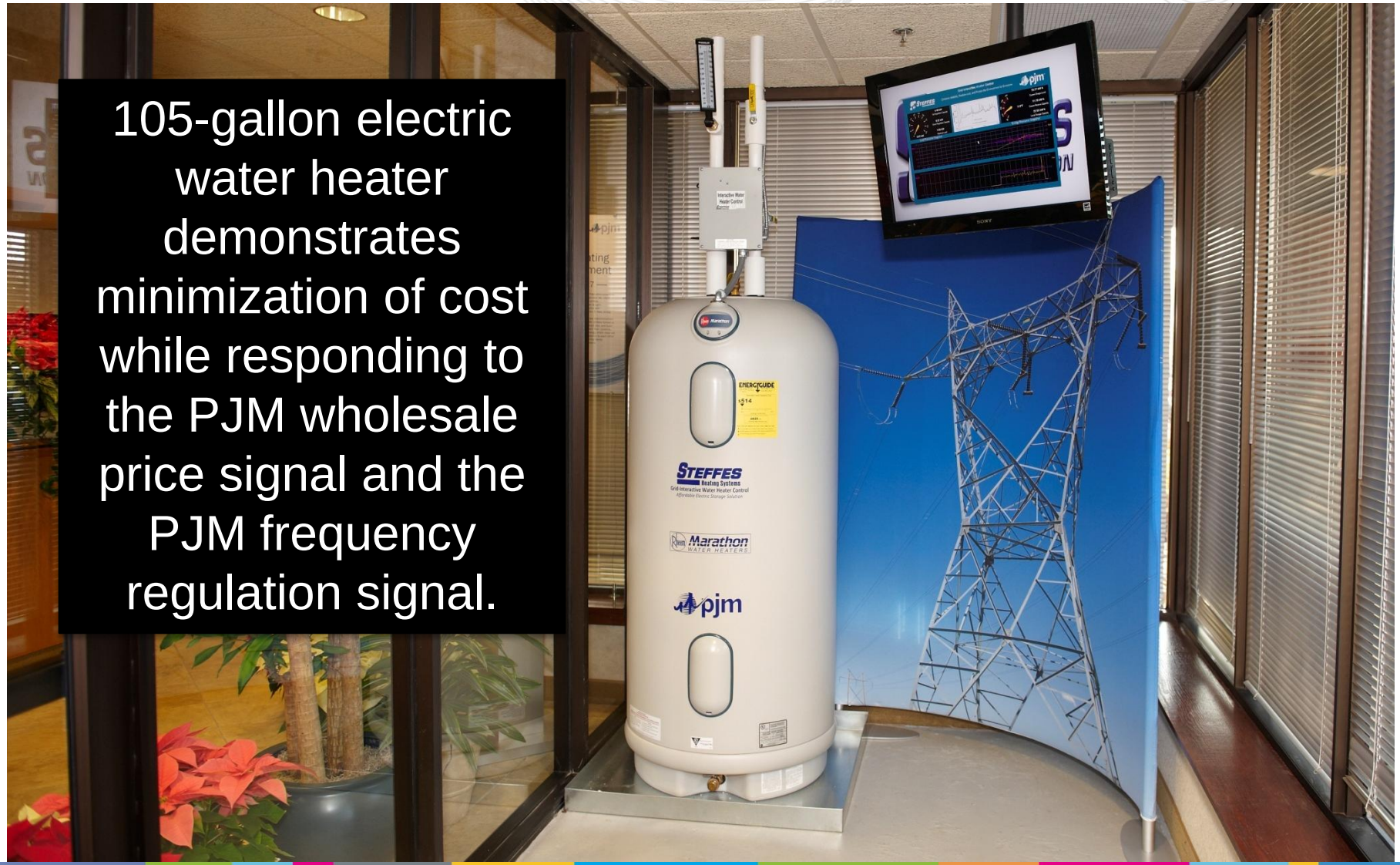
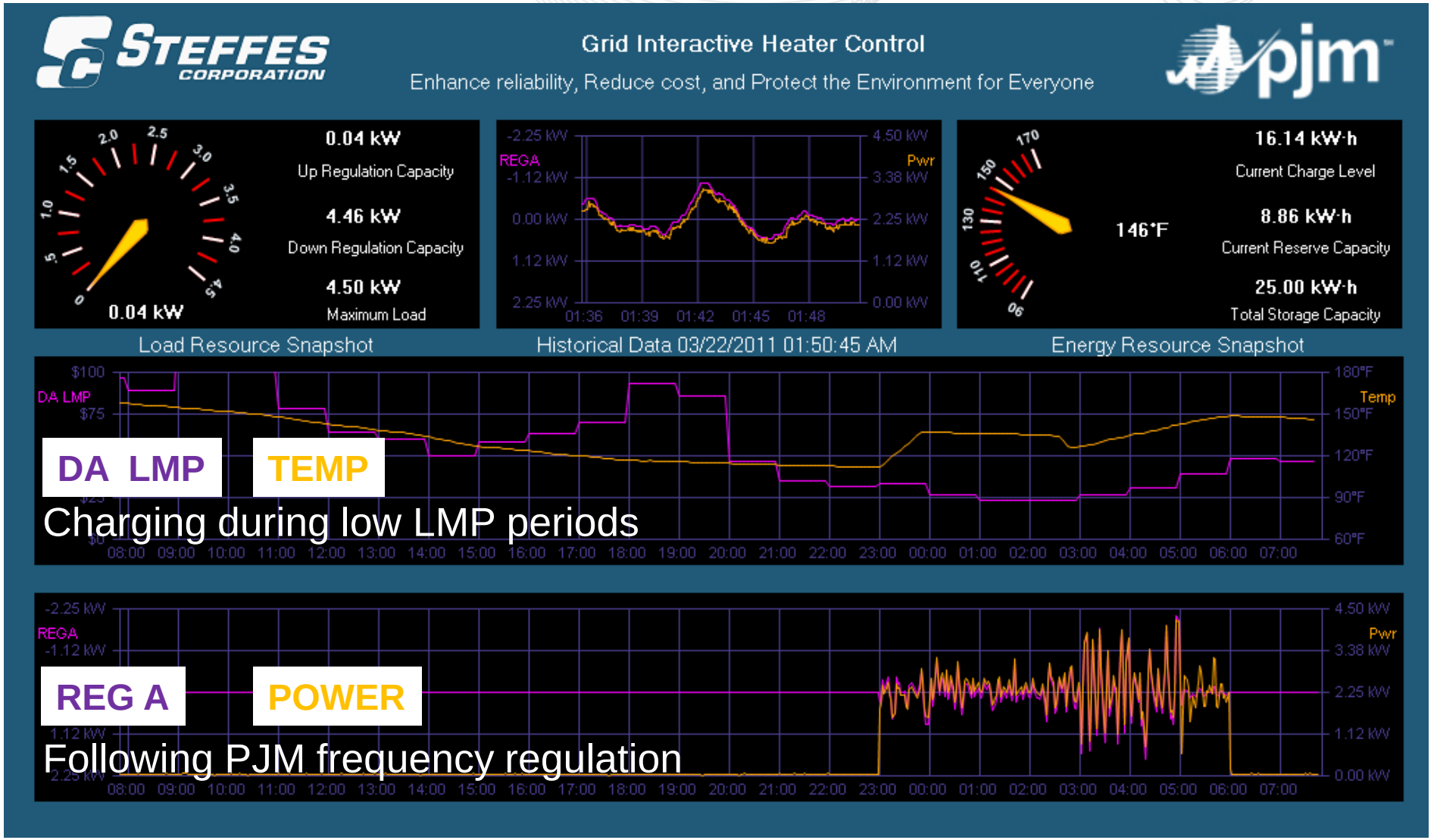
Water Heater



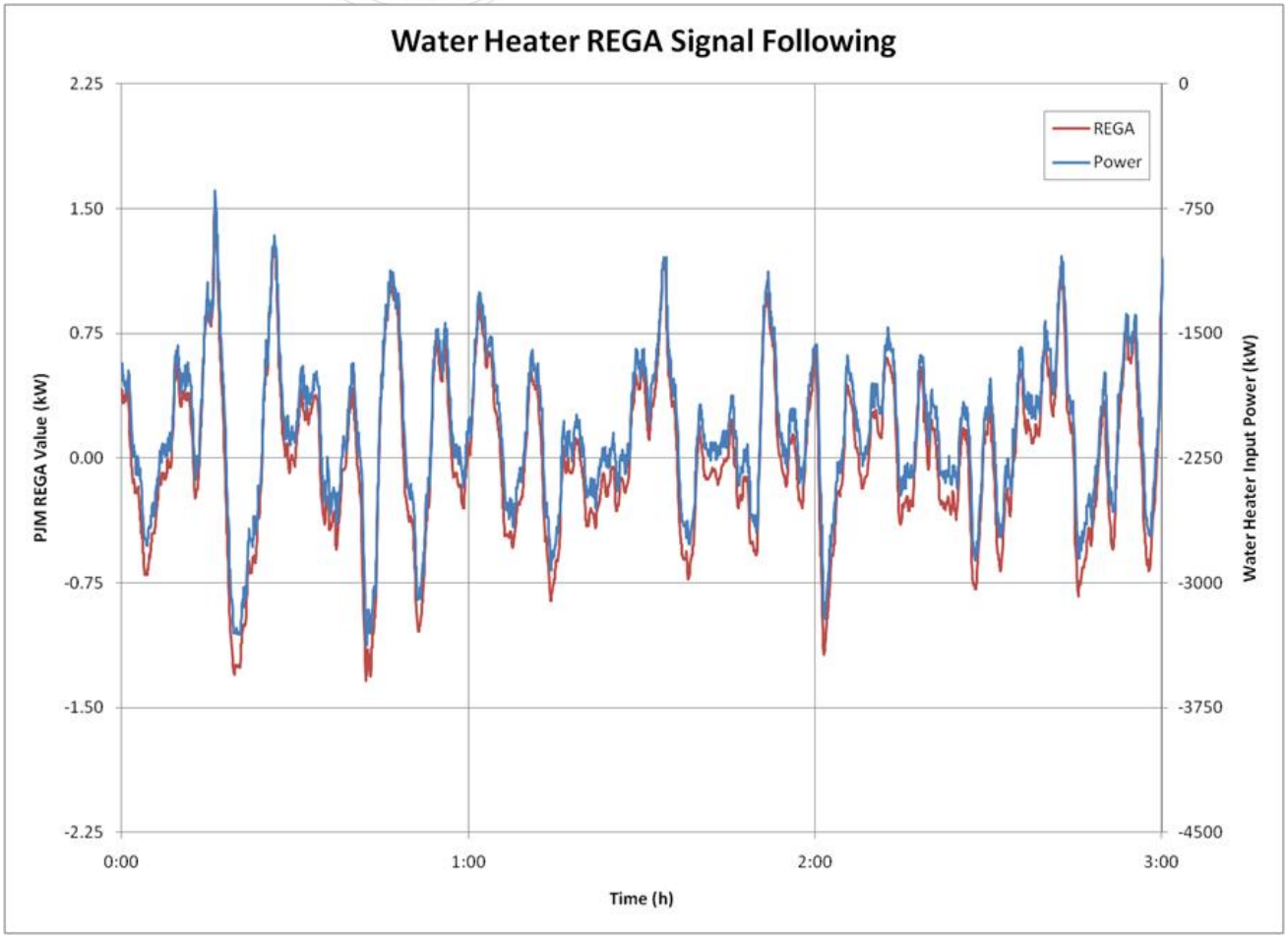
Water Heater – Optimization of LMP and Frequency Regulation



Fast Regulation: Speed Matters…

- PJM Frequency Regulation Signal

- Water heater power consumption +/- 2.25 Kw base point



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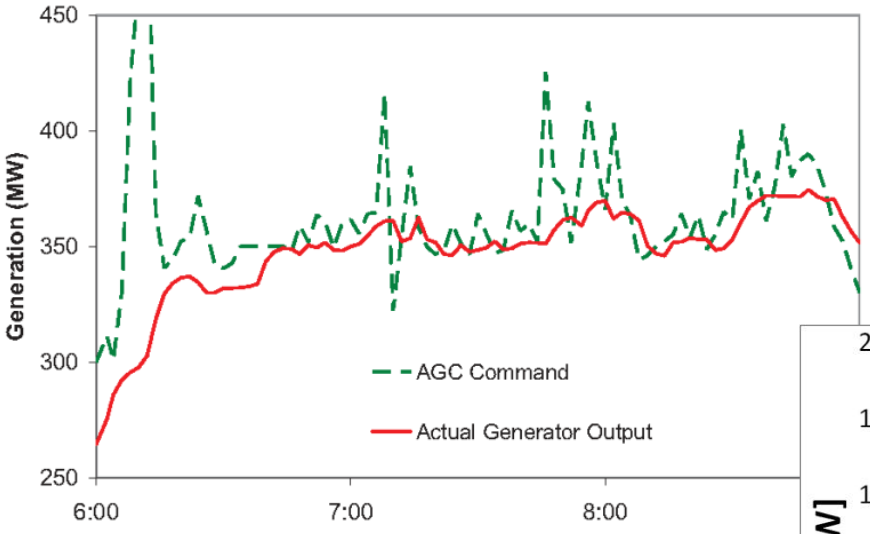
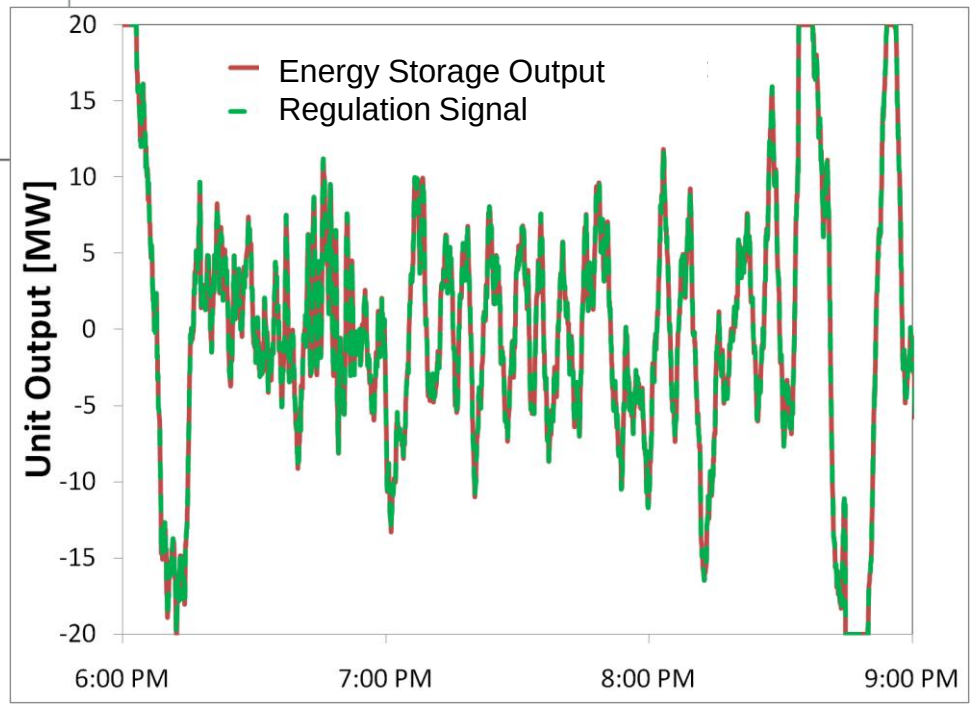


A fossil power plant following a regulation command signal

Energy Storage (batteries / flywheels) accurately following a regulation command signal



The Intersection of Markets, Reliability, Operations, and Technology

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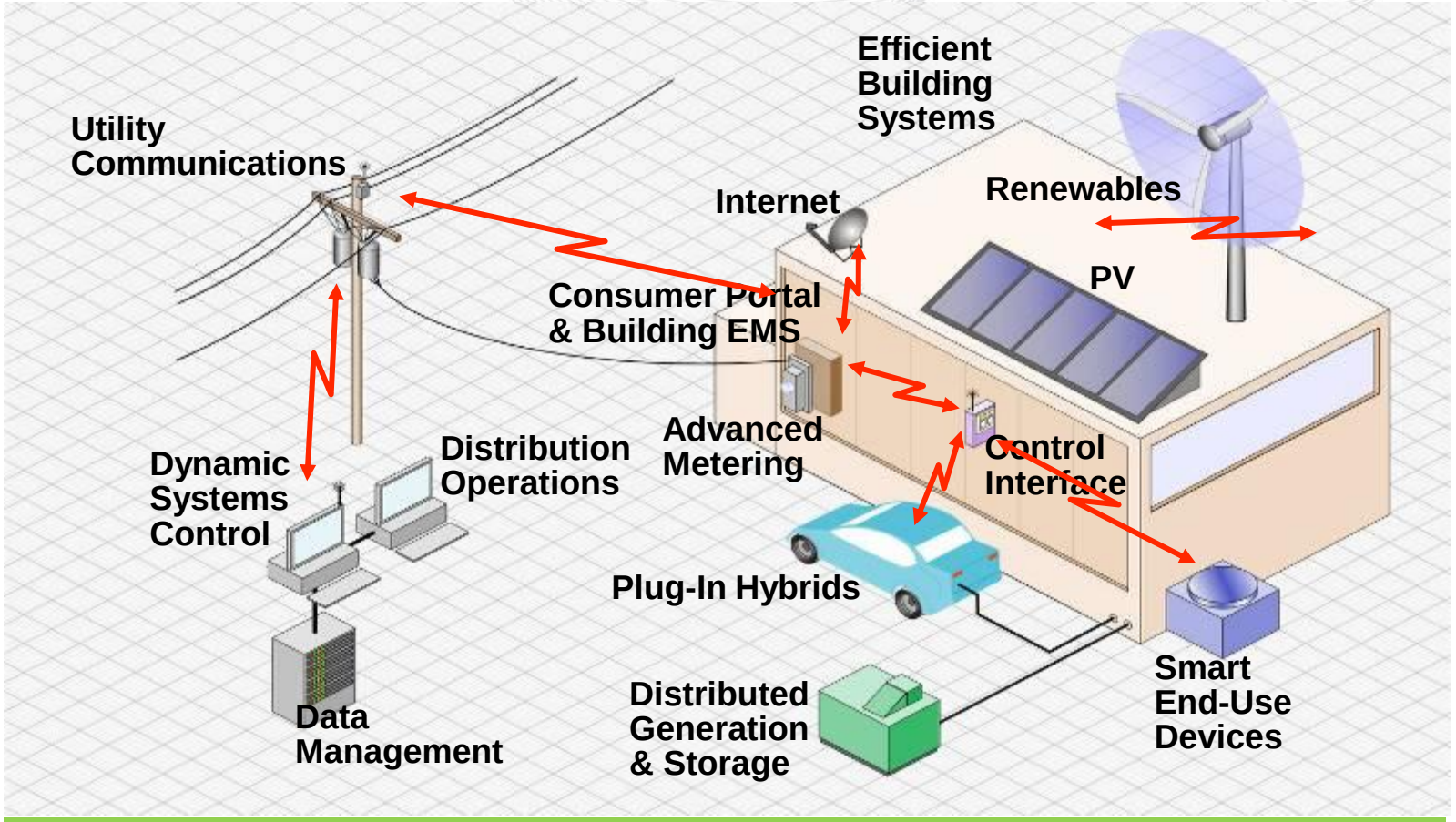
Intelligent Grid & Metering



Tomorrow's intelligent power delivery infrastructure must enable PHEV

--Source: EPRI

Smart Grid Network