Analysis of the Impact of Demand Curtailment on Power Prices

National Action Plan for Energy Efficiency
Mid-Atlantic Implementation Meeting
April 30, 2007

Agenda

- Executive Summary
- Methodology and Findings
- Other Benefits
- Offsets Not Considered

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- Suggested Future Research

Estimate the value of mitigating peak market prices through demand curtailment.

- Using a simulation model, quantify customers' LMP savings (net of FTR revenues) from curtailing demand by 3% in the top twenty 5-hr LMP blocks that occurred within BGE, Delmarva, PECO, PEPCO and PSEG during 2005.
- Perform analyses under actual market conditions and under a range of alternative loads and fuel prices: weather normalized, high peak, low peak, high fuel, and low fuel.

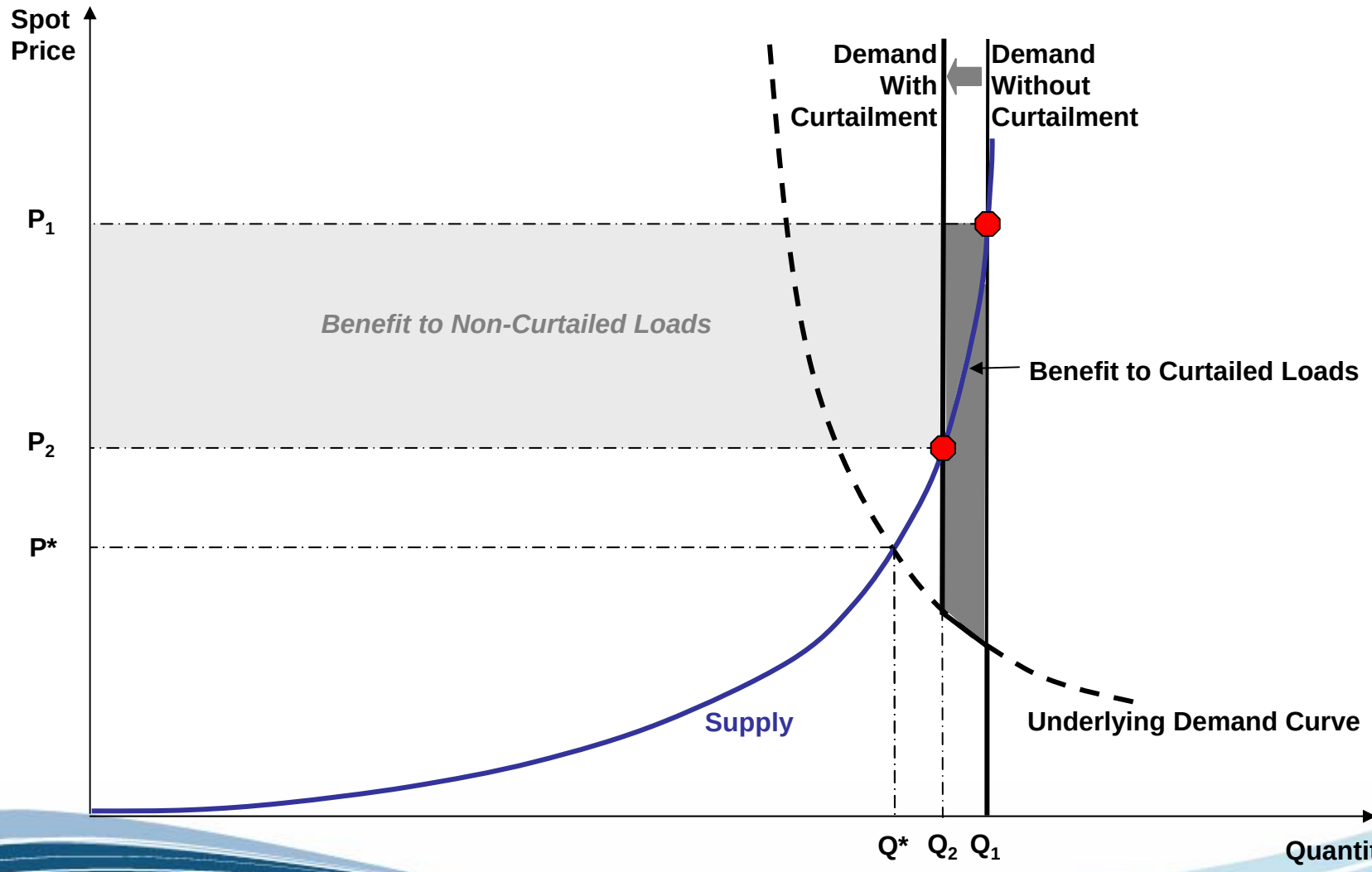
What We Quantified

- Primary focus: energy market impacts and benefits to non-curtailed loads
- Additional rough estimates: energy and capacity benefits to curtailed loads

What We Did NOT Quantify

- Other benefits: competitiveness, price stability, insurance, real-time response, capacity market impacts, T&D savings.
- Secondary market effects that could significantly offset benefits to non-curtailed loads
- Environmental implications

Conceptual Framework for Energy Benefits



Summary of Findings

	Energy Benefits to Non-Curtailed Load	Energy Benefits to Curtailed Load	Capacity Benefits to Curtailed Load
Annual Benefits to MADRI States *from 3% curtailment in five zones in 100 hrs (0.9% reduction in PJM peak load)*	**$83-184 Million** (**5-8%** price reduction in curtailed hours)	**$10-28 Million** (**$100-250/MWh** benefit in curtailed hours)	**$73 Million** (assuming **$58/kW-Yr)**

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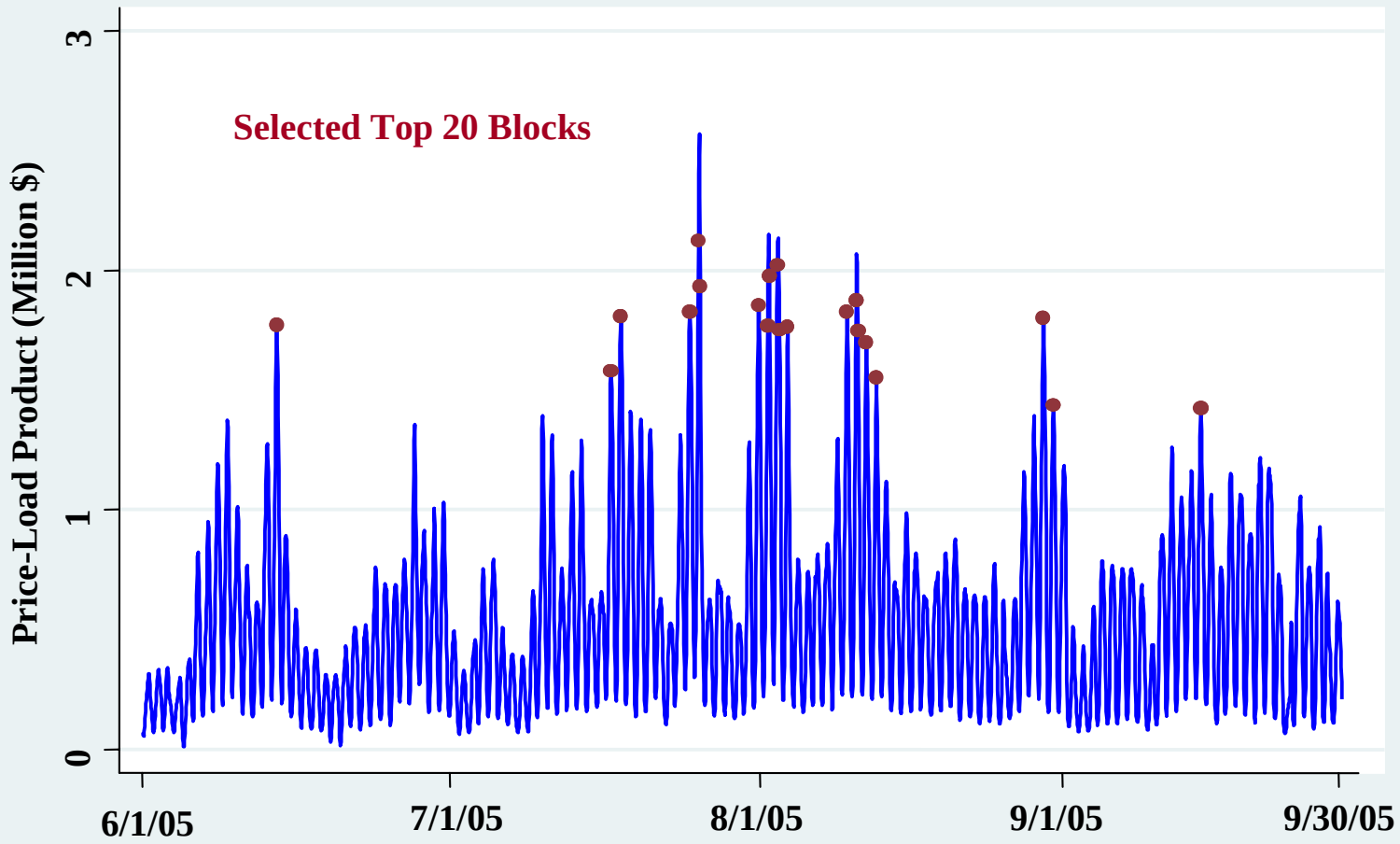
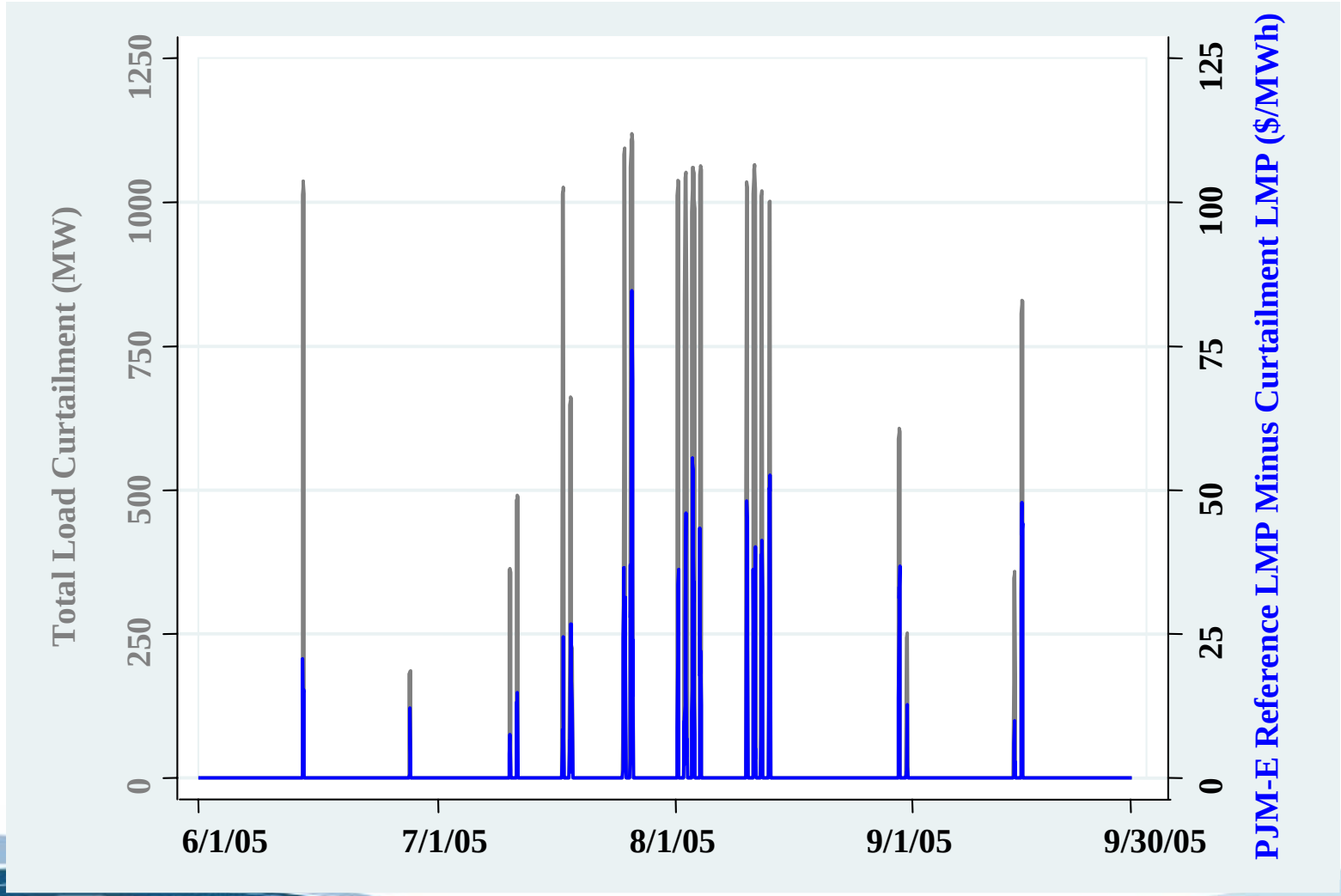
Identification of Top Twenty 5-hour Blocks in PSEG



The plot shows 5-hour moving averages of the hourly price-load products.
"Hourly price-load product" defined as Dayzer simulated LMP multiplied by real-time load in the corresponding hour.

Development of Curtailment Cases

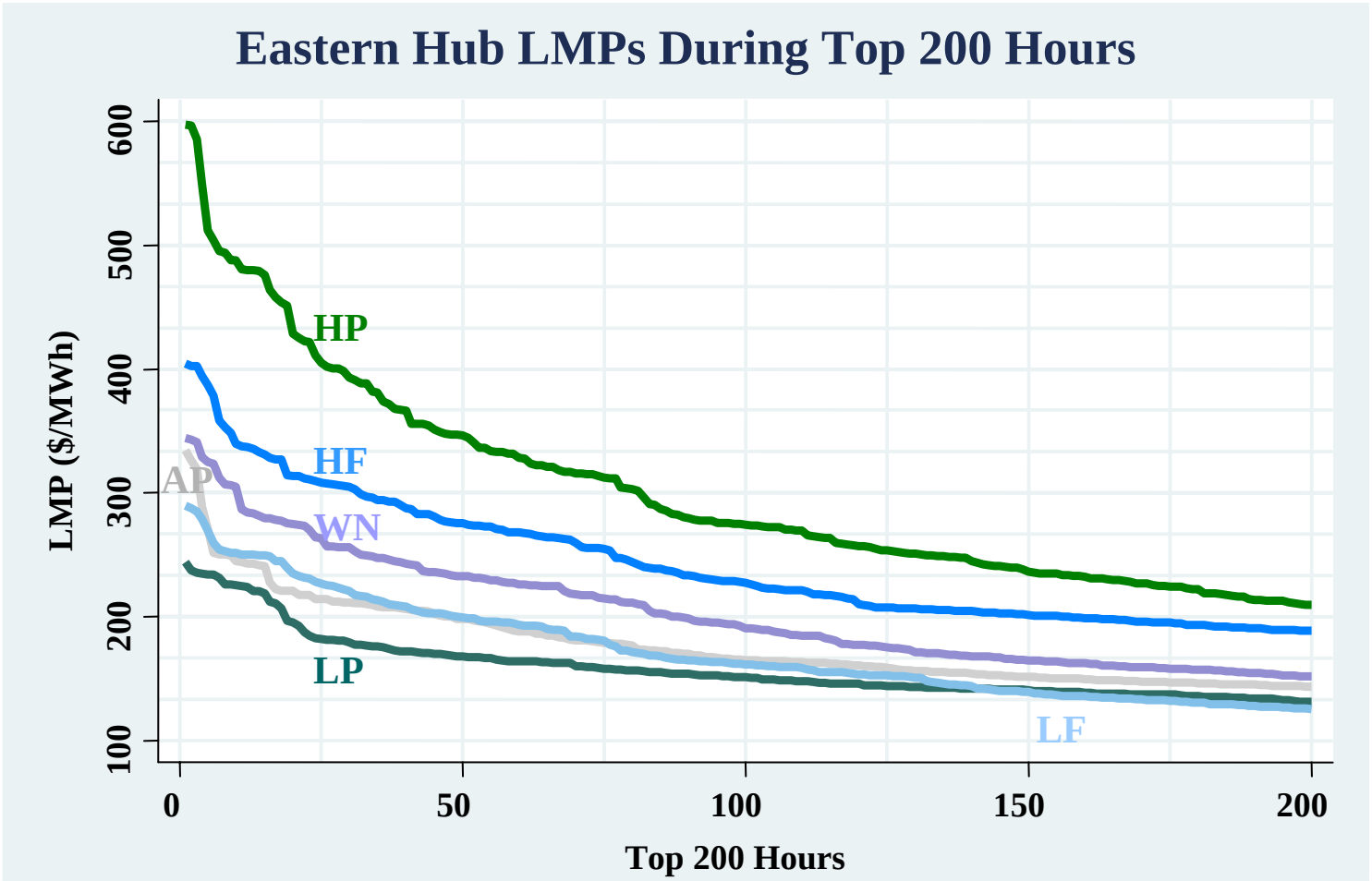
Price Impact of Load Curtailment



•Normalized Case (N): **normalize load, fuel prices, and emission allowance prices.**

•High Peak (HP) and Low Peak (LP) Cases: **±6% of normalized load; normalized fuel and emission allowance prices.**

•High Fuel (HF) and Low Fuel (LF) Cases: **based on 2007 forward prices, with high and low based on historical distributions of spot relative to forward; normalized emission allowance prices; weather-normalized load.**


Eastern Hub LMPs During Top 200 Hours
LMP ($/MWh)
100
200
300
400
500
600
0
50
100
150
200
Top 200 Hours
HP
HF
AP
WN
LP
LF

Benefits to Non-Curtailed Loads

- Gross Savings = Reduction in Zonal LMP * Residual Zonal Load

- Net Savings = Gross Savings – Change in Customer ARR Value
  - PJM provided ARR allocations
  - *Brattle* wrote program to value ARR portfolios with and without demand curtailment

- Report gross and net customer savings for each MADRI state
  - For multi-state zones, allocate savings according to shares of retail sales

Benefits to Non-Curtailed Loads

	Weighted Average LMP Reduction		Average Load Curtailment		Average Residual Load (MW) [E]	Gross Direct Benefits (Million $) [F]	ARR Change (Million $) [G]	Net Direct Benefits (Million $) [H]
	($/MWh) [A]	(%) [B]	(MW) [C]	(%) [D]				
Actual Peak (AP) Case ***(during 137 hours in which load is curtailed in at least one zone)***								
PA	**$11**	**5.8%**	**172**	**0.7%**	**25,514**	**$36.7**	**($6.3)**	**$30.4**
NJ	**$12**	**6.7%**	**211**	**1.2%**	**17,640**	**$30.1**	**($1.5)**	**$28.6**
DE	**$21**	**10.6%**	**57**	**2.2%**	**2,482**	**$7.3**	**($1.6)**	**$5.7**
MD	**$12**	**6.0%**	**259**	**2.0%**	**12,886**	**$20.8**	**($4.3)**	**$16.5**
DC	**$13**	**6.0%**	**41**	**2.2%**	**1,791**	**$3.1**	**($0.9)**	**$2.2**
MADRI Total	**$12**	**6.7%**	**740**	**1.2%**	**60,313**	**$98.0**	**($14.6)**	**$83.4**
Normalized (N) Case (147 hours)								
PA	**$11**	**5.2%**	**167**	**0.6%**	**26,435**	**$42.4**	**($8.8)**	**$33.6**
NJ	**$14**	**6.4%**	**208**	**1.1%**	**18,356**	**$36.5**	**($1.5)**	**$35.0**
DE	**$27**	**11.9%**	**53**	**2.1%**	**2,537**	**$10.0**	**($2.7)**	**$7.2**
MD	**$15**	**6.4%**	**252**	**1.8%**	**13,501**	**$29.3**	**($6.1)**	**$23.2**
DC	**$17**	**7.1%**	**40**	**2.1%**	**1,877**	**$4.8**	**($1.3)**	**$3.5**
MADRI Total	**$13**	**7.1%**	**721**	**1.1%**	**62,705**	**$123.0**	**($20.5)**	**$102.5**

[A] and [B]: LMP reduction is weighted by hourly residual load.
[F] = [A] x [E] x number of hours with at least one zone curtailed.
[G]: 97% calculated ARRs are allocated to direct benefits; rest allocated to participant benefits.
[H] = [F] + [G].

Benefits to Non-Curtailed Loads (cont.)

	Weighted Average LMP Reduction		Average Load Curtailment		Average Residual Load (MW) [E]	Gross Direct Benefits (Million $) [F]	ARR Change (Million $) [G]	Net Direct Benefits (Million $) [H]
	($/MWh) [A]	(%) [B]	(MW) [C]	(%) [D]				
High Peak (HP) Case (133 hours)								
PA	**$23**	**6.7%**	**195**	**0.7%**	**28,158**	**$84.5**	**($21.9)**	**$62.6**
NJ	**$26**	**8.0%**	**244**	**1.2%**	**19,581**	**$67.9**	**($2.2)**	**$65.6**
DE	**$37**	**10.4%**	**62**	**2.3%**	**2,668**	**$13.1**	**($1.2)**	**$11.9**
MD	**$24**	**7.4%**	**295**	**2.0%**	**14,277**	**$45.3**	**($7.2)**	**$38.1**
DC	**$25**	**7.8%**	**46**	**2.3%**	**1,984**	**$6.7**	**($1.4)**	**$5.3**
MADRI Total	**$25**	**7.9%**	**842**	**1.2%**	**66,668**	**$217.5**	**($33.9)**	**$183.6**
Low Peak (LP) Case (151 hours)								
PA	**$7**	**4.3%**	**152**	**0.6%**	**24,936**	**$27.2**	**($7.9)**	**$19.3**
NJ	**$9**	**5.3%**	**191**	**1.1%**	**17,252**	**$23.1**	**($1.5)**	**$21.6**
DE	**$10**	**5.8%**	**48**	**2.0%**	**2,375**	**$3.5**	**($0.2)**	**$3.3**
MD	**$8**	**4.8%**	**230**	**1.8%**	**12,703**	**$15.8**	**($4.0)**	**$11.9**
DC	**$9**	**5.0%**	**36**	**2.0%**	**1,770**	**$2.4**	**($0.7)**	**$1.6**
MADRI Total	**$8**	**5.0%**	**657**	**1.1%**	**59,036**	**$72.0**	**($14.3)**	**$57.6**

[A] and [B]: LMP reduction is weighted by hourly residual load.
[F] = [A] x [E] x number of hours with at least one zone curtailed.
[G]: 97% calculated ARRs are allocated to direct benefits; rest allocated to participant benefits.
[H] = [F] + [G].

Benefits to Non-Curtailed Loads (cont.)

	Weighted Average LMP Reduction		Average Load Curtailment		Average Residual Load (MW) [E]	Gross Direct Benefits (Million $) [F]	ARR Change (Million $) [G]	Net Direct Benefits (Million $) [H]
	($/MWh) [A]	(%) [B]	(MW) [C]	(%) [D]				
High Fuel (HF) Case (135 hours)								
PA	**$15**	**6.0%**	**182**	**0.7%**	**26,571**	**$53.6**	**($9.0)**	**$44.6**
NJ	**$19**	**7.3%**	**227**	**1.2%**	**18,444**	**$46.5**	**($1.6)**	**$44.9**
DE	**$32**	**12.0%**	**58**	**2.2%**	**2,533**	**$11.1**	**($2.6)**	**$8.5**
MD	**$19**	**6.8%**	**274**	**2.0%**	**13,504**	**$33.9**	**($6.0)**	**$27.9**
DC	**$21**	**7.5%**	**43**	**2.2%**	**1,877**	**$5.4**	**($1.3)**	**$4.1**
MADRI Total	**$18**	**7.6%**	**785**	**1.2%**	**62,929**	**$150.5**	**($20.5)**	**$129.9**
Low Fuel (LF) Case (152 hours)								
PA	**$9**	**5.2%**	**160**	**0.6%**	**26,357**	**$36.3**	**($7.9)**	**$28.4**
NJ	**$12**	**6.8%**	**201**	**1.1%**	**18,233**	**$33.5**	**($1.8)**	**$31.6**
DE	**$23**	**12.4%**	**52**	**2.0%**	**2,520**	**$9.0**	**($2.5)**	**$6.5**
MD	**$13**	**6.6%**	**244**	**1.8%**	**13,456**	**$26.1**	**($5.5)**	**$20.6**
DC	**$15**	**7.2%**	**38**	**2.0%**	**1,874**	**$4.3**	**($1.2)**	**$3.1**
MADRI Total	**$11**	**7.3%**	**696**	**1.1%**	**62,441**	**$109.1**	**($18.9)**	**$90.2**

[A] and [B]: LMP reduction is weighted by hourly residual load.
[F] = [A] x [E] x number of hours with at least one zone curtailed.
[G]: 97% calculated ARRs are allocated to direct benefits; rest allocated to participant benefits.
[H] = [F] + [G].

Benefits Are Smaller When Only One Zone Is Curtailed

Market Impacts if Curtailment Occurs in Only One Zone (Normalized Case)

	Only One Zone Curtailed							All Curtailed
	Weighted Average LMP Reduction		Average Curtailed Load (MW)	Average Residual Load (MW)	Gross Benefit (Million $)	ARR Change (Million $)	Net Benefit (Million $)	Net Benefit (Million $)
	($/MWh) [A]	(%) [B]	[C]	[D]	[E]	[F]	[G]	[H]
BGE	$6	2.8%	204	6,597	$4.2	($0.7)	$3.5	$12.1
Delmarva	$23	10.3%	115	3,706	$8.6	($4.2)	$4.4	$10.6
PECO	$9	4.2%	246	7,939	$7.0	($1.9)	$5.1	$14.9
PEPCO	$14	5.6%	193	6,255	$8.5	($3.1)	$5.4	$11.6
PSEG	$8	3.8%	306	9,902	$8.2	($1.1)	$7.0	$19.4

[A]: LMP reduction is weighted by hourly residual load.
[E] = [A] x [D] x 100 (number of hours with at least one zone curtailed).
[G] = [E] + [F].

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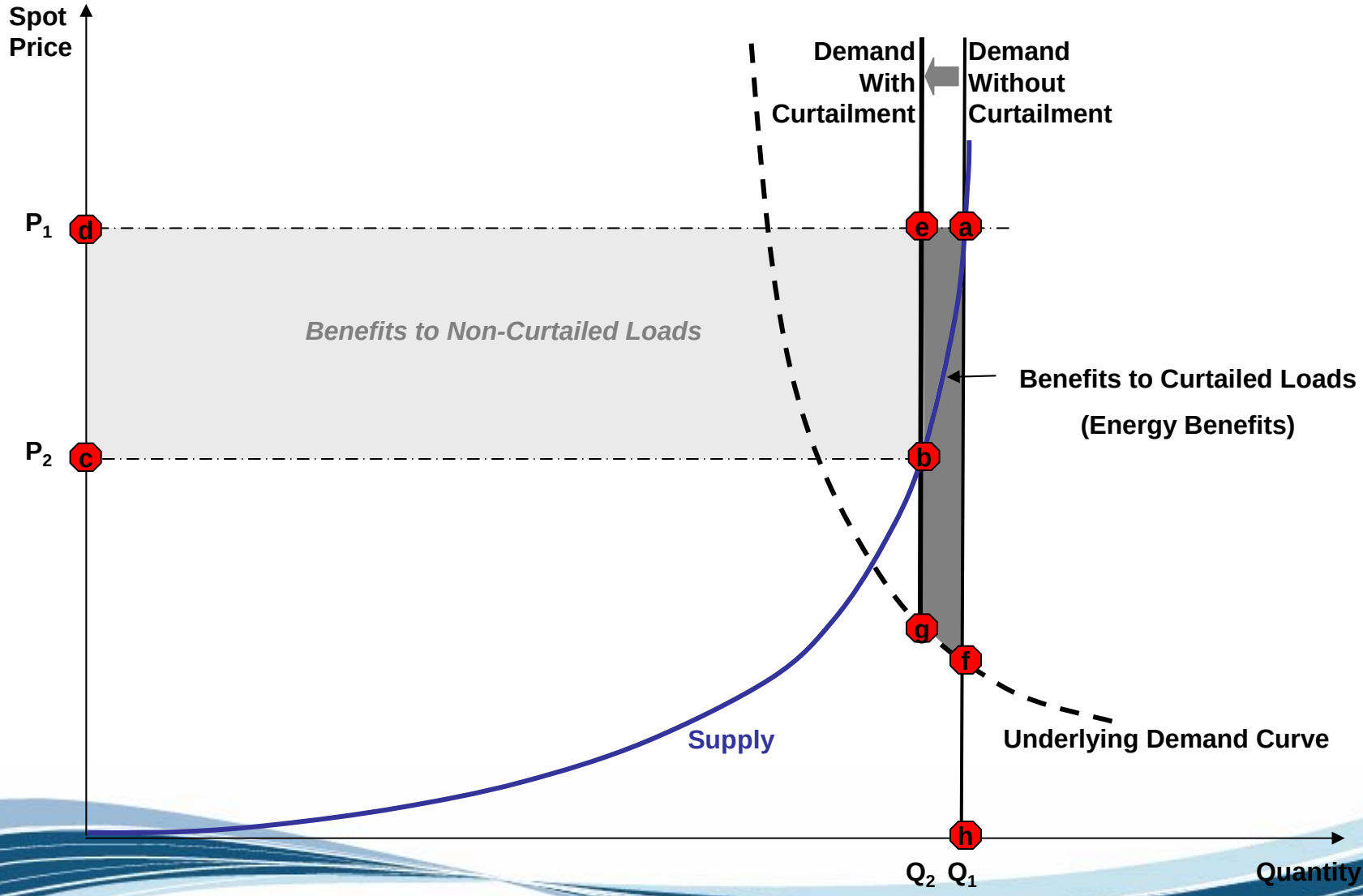
Conceptual Framework



Energy Benefits to Curtailed Loads

	Average Curtailed Load (MW) [A]	Benefits to Curtailed Loads ($/MWh)			Benefits to Curtailed Loads (Million $)		
		Lower Bound [B]	Intermediate Estimate [C]	Upper Bound [D]	Lower Bound [E]	Intermediate Estimate [F]	Upper Bound [G]
Actual Peak (AP) Case							
PA	**236**	**$15**	**$119**	**$178**	**$0.4**	**$2.8**	**$4.2**
NJ	**289**	**$15**	**$74**	**$183**	**$0.4**	**$2.1**	**$5.3**
DE	**78**	**$19**	**$136**	**$190**	**$0.2**	**$1.1**	**$1.5**
MD	**355**	**$13**	**$138**	**$189**	**$0.5**	**$4.9**	**$6.7**
DC	**56**	**$12**	**$144**	**$194**	**$0.1**	**$0.8**	**$1.1**
MADRI Total	**1,014**	**$15**	**$115**	**$185**	**$1.5**	**$11.7**	**$18.8**
Normalized (N) Case							
PA	**246**	**$18**	**$153**	**$213**	**$0.4**	**$3.8**	**$5.2**
NJ	**306**	**$18**	**$101**	**$211**	**$0.5**	**$3.1**	**$6.5**
DE	**79**	**$26**	**$164**	**$218**	**$0.2**	**$1.3**	**$1.7**
MD	**371**	**$18**	**$164**	**$216**	**$0.7**	**$6.1**	**$8.0**
DC	**58**	**$18**	**$173**	**$223**	**$0.1**	**$1.0**	**$1.3**
MADRI Total	**1,060**	**$18**	**$144**	**$214**	**$2.0**	**$15.2**	**$22.7**

[E], [F], [G]: Benefits are net of changes in ARR value.
[B] = [E] / ([A] x 100 Hours). Similar formula applies for [C] and [D].

Energy Benefits to Curtailed Loads (cont.)

	Average Curtailed Load (MW) [A]	Benefits to Curtailed Loads ($/MWh)			Benefits to Curtailed Loads (Million $)		
		Lower Bound [B]	Intermediate Estimate [C]	Upper Bound [D]	Lower Bound [E]	Intermediate Estimate [F]	Upper Bound [G]
High Peak (HP) Case							
PA	**259**	**$34**	**$263**	**$323**	**$0.9**	**$6.8**	**$8.4**
NJ	**324**	**$31**	**$199**	**$310**	**$1.0**	**$6.5**	**$10.1**
DE	**83**	**$42**	**$290**	**$343**	**$0.3**	**$2.4**	**$2.8**
MD	**392**	**$28**	**$262**	**$314**	**$1.1**	**$10.3**	**$12.3**
DC	**62**	**$25**	**$276**	**$326**	**$0.2**	**$1.7**	**$2.0**
MADRI Total	**1,120**	**$31**	**$247**	**$318**	**$3.5**	**$27.7**	**$35.6**
Low Peak (LP) Case							
PA	**230**	**$10**	**$109**	**$169**	**$0.2**	**$2.5**	**$3.9**
NJ	**290**	**$11**	**$59**	**$168**	**$0.3**	**$1.7**	**$4.9**
DE	**74**	**$12**	**$113**	**$166**	**$0.1**	**$0.8**	**$1.2**
MD	**350**	**$9**	**$117**	**$169**	**$0.3**	**$4.1**	**$5.9**
DC	**55**	**$8**	**$121**	**$170**	**$0.0**	**$0.7**	**$0.9**
MADRI Total	**999**	**$10**	**$98**	**$169**	**$1.0**	**$9.8**	**$16.8**

[E], [F], [G]: Benefits are net of changes in ARR value.

[B] = [E] / ([A] x 100 Hours). Similar formula applies for [C] and [D].

Energy Benefits to Curtailed Loads (cont.)

	Average Curtailed Load (MW) [A]	Benefits to Curtailed Loads ($/MWh)			Benefits to Curtailed Loads (Million $)		
		Lower Bound [B]	Intermediate Estimate [C]	Upper Bound [D]	Lower Bound [E]	Intermediate Estimate [F]	Upper Bound [G]
High Fuel (HF) Case							
PA	**246**	**$23**	**$195**	**$255**	**$0.6**	**$4.8**	**$6.3**
NJ	**306**	**$24**	**$143**	**$253**	**$0.7**	**$4.4**	**$7.7**
DE	**78**	**$31**	**$208**	**$261**	**$0.2**	**$1.6**	**$2.0**
MD	**370**	**$22**	**$205**	**$257**	**$0.8**	**$7.6**	**$9.5**
DC	**58**	**$21**	**$212**	**$262**	**$0.1**	**$1.2**	**$1.5**
MADRI Total	**1,059**	**$23**	**$185**	**$256**	**$2.5**	**$19.6**	**$27.1**
Low Fuel (LF) Case							
PA	**244**	**$16**	**$118**	**$177**	**$0.4**	**$2.9**	**$4.3**
NJ	**306**	**$16**	**$67**	**$175**	**$0.5**	**$2.1**	**$5.4**
DE	**78**	**$23**	**$130**	**$183**	**$0.2**	**$1.0**	**$1.4**
MD	**371**	**$16**	**$127**	**$178**	**$0.6**	**$4.7**	**$6.6**
DC	**58**	**$16**	**$136**	**$186**	**$0.1**	**$0.8**	**$1.1**
MADRI Total	**1,058**	**$16**	**$108**	**$178**	**$1.7**	**$11.4**	**$18.8**

[E], [F], [G]: Benefits are net of changes in ARR value.

[B] = [E] / ([A] x 100 Hours). Similar formula applies for [C] and [D].

Capacity Benefits to Curtailed Loads

Capacity Benefits = Reduction in Normalized Peak Load (MW)
x 1.15 Reserve Margin
x Long-Run Marginal Cost of Capacity ($/kW-Yr)

= 1100 MW x 1.15 x $58/kW-Yr

= **$73 Million**

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  - Enhanced Market Competition
  - Reduced Price Volatility
  - Insurance Against Extreme Events
  - Real-Time vs. Day-Ahead Curtailments
  - Capacity Market Impacts
  - Avoided/Deferred T&D Costs
- Offsets Not Considered
- Suggested Future Research

Enhanced Market Competition

- Expanding demand response programs, including curtailment programs, would increase the elasticity of demand and thereby increase the competitiveness of the market.

- Simple game-theoretical models suggest that doubling the elasticity of demand would enhance competitiveness as much as reducing market concentration by 50%.

- Enhanced competitiveness could result in lower energy prices and lower capacity prices both in the short term and the long term.

Reduced Price Volatility and Rate Variance

- Most end-use customers are risk-averse.
- There is value to reducing the price variance, not just reducing expected prices, faced by customers.

Insurance Against Extreme Events

- There are many possible events that could add disproportionately to the overall probability-weighted value of curtailment.

- Such events include the coincident outages of major generators and transmission lines or extreme heat wave occurring in shoulder months when many generators are on maintenance.

- The value of demand curtailment could be quantified more completely by simulating such extreme, low-probability events.

Capacity Market Impacts

- Demand response could reduce capacity prices by reducing peak loads and therefore reducing the demand for capacity.

- With reduced demand, the capacity market could clear at a lower price, more so in the short-run than the long-run.

Real-Time vs. Day-Ahead Curtailments

- DR is likely to be more valuable in RT vs. DA.
- In the long-term, RT and DA prices should converge, perhaps subject to a risk premium
- But RT markets tend to be more volatile and have higher price spikes than DA.
- Hence, load curtailment can have the greatest price impact if “dispatchable” in real-time, mitigating unexpectedly tight market conditions.
- As modeled, benefits may underestimate the benefit of DR

Avoided/Deferred T&D Costs

- PDR may be able to avoid or defer transmission and distribution (T&D)
- These benefits, if they do occur, are likely to be larger for distribution than transmission
- The magnitude of these benefits depend on the location of the DR
- Distribution benefits may or may not occur in areas with high DA or RT energy prices

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  - Load Shifting and Demand Elasticity
  - Long-Term Equilibrium: Accelerated Retirements, Delayed Construction, Capacity Price Increases
  - Costs of DR Programs

Shifting of Load

- Shifting of curtailed load to other hours mitigates some of the calculated benefits of DR

- Some DR will not result in load shifting

- Some of this load shifting may occur to other hours in the curtailment blocks;

Capacity Shifts in Long-term Equilibrium

•If DR reduces recovery of fixed costs necessary for an existing generation unit to stay in the market, then that unit could retire; construction of new capacity could be delayed.

•This reduction in installed capacity would increase electricity prices, although this increase will likely be less than the short-term reduction in prices due to DR.

•In addition, in a competitive market equilibrium, reduced energy prices would likely be offset by higher capacity prices, as suppliers raise their capacity bids to recover their going-forward fixed costs.

•This study has not analyzed where and when competitive equilibrium conditions can be expected, how long it will take for the energy market impact to be offset by capacity effects, or how complete the resulting offset is likely to be.

Environmental Effects not Considered

- Environmental effects are probably small and not necessarily beneficial
- 3% reduction in demand in 1% of the hours reduces total megawatt-hours by 0.03%, assuming no shift in demand
- Some major emissions are capped or soon to be capped
- Similarly, some units' emissions are limited by maximum-run-hour constraints or by emissions limits imposed by their environmental permits
- If curtailed load runs behind-the-meter generation to effectuate its load reduction, then the environmental effects may be negative
- However, demand reductions during periods of peak load might achieve modest environmental benefits by reducing generation of the dirtiest plants in load centers on the hottest, smoggiest days.