Price Formation with Evolving Resource Mix

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Purpose

- Overview MISO evolving landscape
- Update recent price enhancements
- Explore continuing price formation

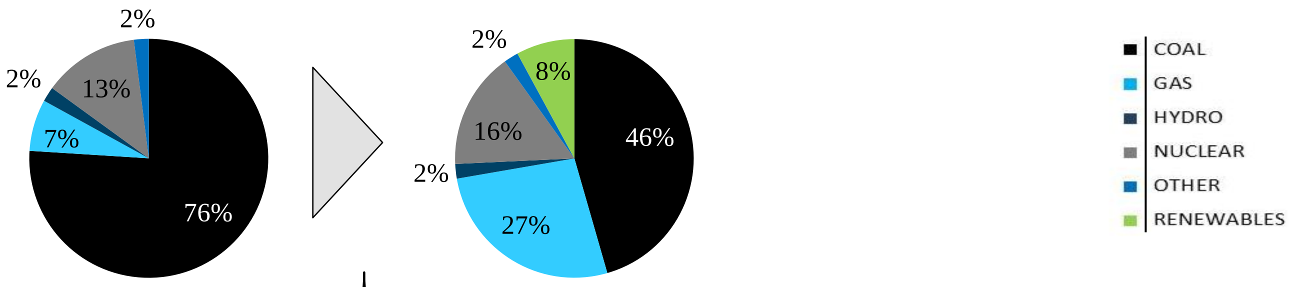
Key Takeaways

- Evolving resource mix drives pricing needs to support reliability and sustainability
- MISO recent price enhancements are producing expected benefits
- Continuing price formation is being explored holistically to prepare for a low-carbon future

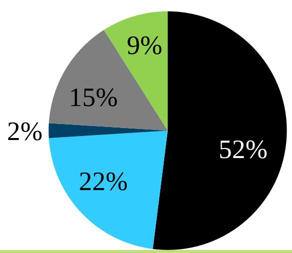
MISO expects evolving resource mix and increasing demand-side participation

MISO Generation Portfolio Evolution

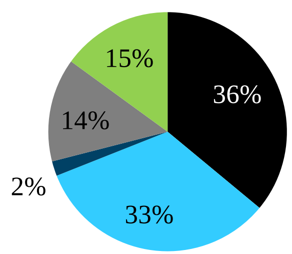
2005 **2016**



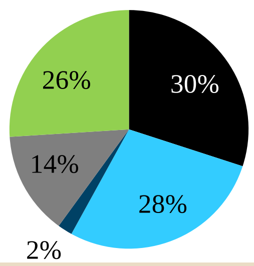
2031 Future Scenarios



Existing Fleet
No carbon regulations modeled but some reductions expected due to RPS and economics.



Policy Regulation
Carbon regulations targeting a 25% reduction across all aggregated unit outputs are enacted.



Accelerated Technology
Increase in carbon emissions results in carbon regulations targeting a 35% reduction across all aggregated unit outputs to be enacted.

Load growth has been low, but demand response is playing an important role

Markets must be designed to enable adequate supply and incentivize efficient market outcomes

Price Formation

- **Out-of-market Payments**: With more renewables, traditional plants (e.g., gas turbines) would cycle more often, but their commitment costs (and dispatch costs if at operating limits) may not be eligible to set prices
- **Resource Flexibility**: Resources may have to be committed or positioned for reliability needs, but are transparent market signals in place to valuate the resource flexibility?
- **Sufficient Reserve Margins**: Sustainability of conventional power plants is impacted by low-marginal costs of Renewables
- …

Demand-Side Participation

- With tightening reserve margins following the retirement of aged coal plants, demand responsiveness becomes very important
- Visibility and bid/offer formats of demand resources can be challenging and ineffective treatment may distort prices

Modeling of Supply

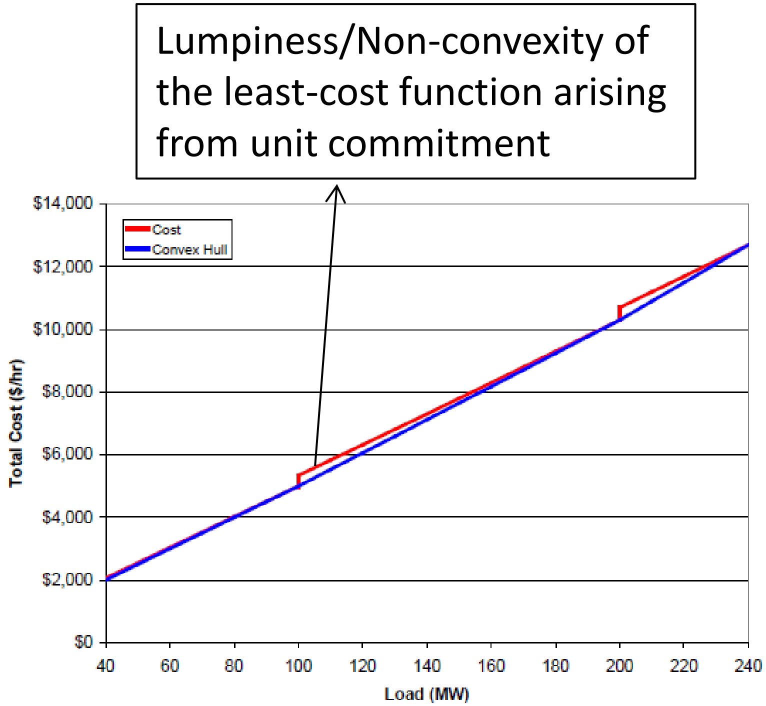
- Storage Resources
- Distributed Energy Resources
- Configuration-based Combined Cycle Modeling
- …

Software Platform

- Computational performance improvement to allow alignment with gas industry
- Market System Evaluation to identify runway of future market enhancements and system extension

Extended LMP more fully and transparently reflects the true costs to meet demand

A pricing approach to effectively price commitment as well as dispatch costs based upon a mathematical concept of "Convex Hull"



Design Objectives	Phase I Results
More fully reflect the costs when resources are committed to meet demand	~$1/MWh increase*
Reduce uplift payments	~1% RSG reduction
More accurately price reserve or transmission shortages when MISO could commit resources to solve the conditions	~$15/MWh decrease*
Reduce price volatility and improve DA/RT price convergence	2.25% Improvement

Phase I modest production results validate design objectives; Phase II was recently implemented to capture broader benefits

*Note: Averaged over relevant Real-Time intervals

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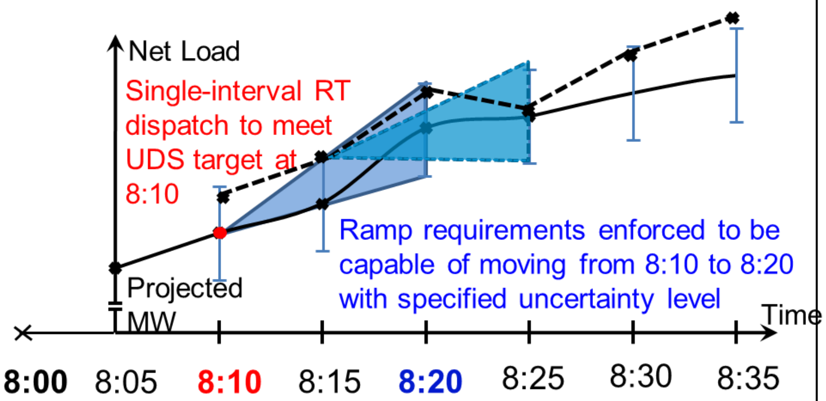
With increasing renewables, resource flexibility becomes a valuable attribute for grid operation

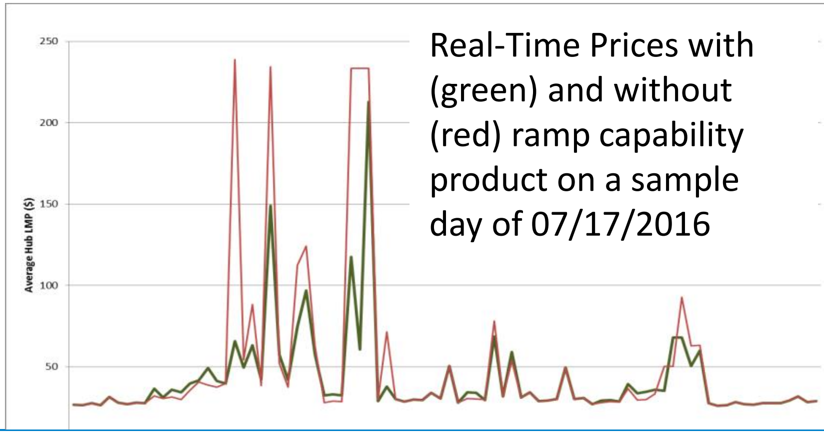
Co-optimized with Energy and Reserves in Day-Ahead & Real-Time

- Up/down ramp requirements are enforced based on anticipated system ramping needs
- Prices are the marginal costs to meet ramp requirements
  - Opportunity cost
  - Ramp Capability Demand Curve



Expected Benefits obtained in Production

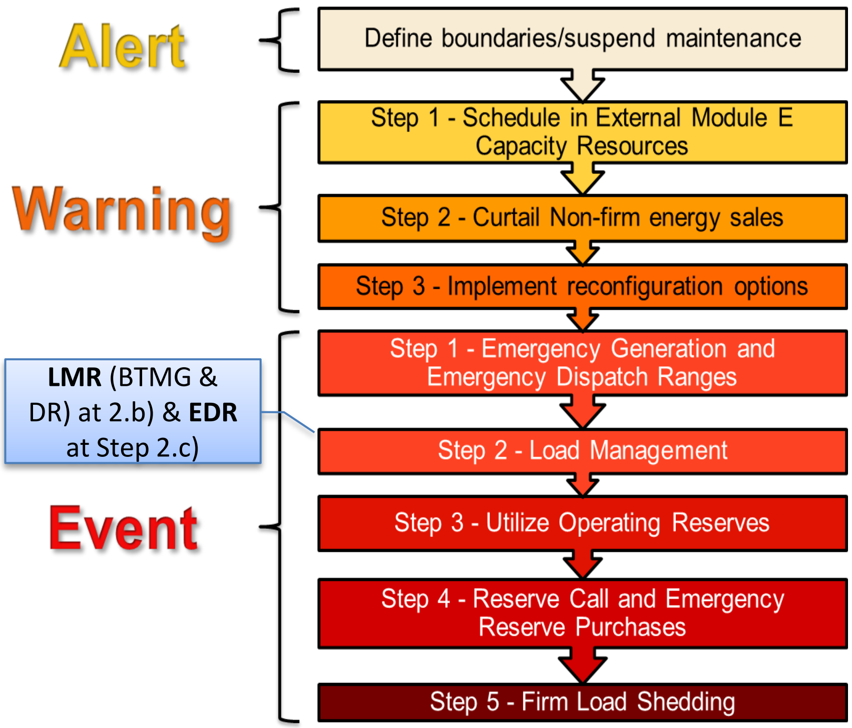
Expected results	Actual Results
Production cost savings	$4.2 million/year
Reduced Price volatility	~7%
Improved Day-Ahead /Real-Time convergence	~3%
Reduced short-term scarcities and price spikes	

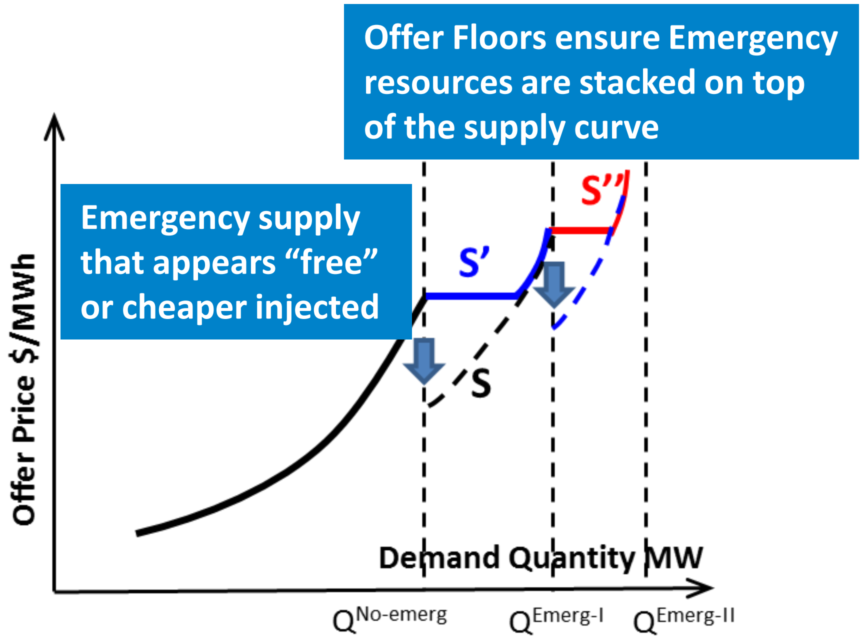


Facing tightening supply margin, Emergency pricing values demand resources and supports reliability

- The RTO progressively accesses Emergency energy & demand resources
- Prices could be depressed due to injection of Emergency supply

- Establish Emergency Offer Floors as the highest available economic and/or emergency offer
- Allow Emergency resources such as LMR to be "partially committed" for pricing purpose





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Moving forward with evolving resource mix ….

Traditional fossil fuel plants cycling on and off more often present more pricing needs

Pricing Needs

- Resources may have to be dispatched at their minimum limits and cannot be turned off within min run times
  - Current ELMP effectively prices units dispatched at limits including their commitment costs, but only treats cost of a single dispatch interval at a time

Research Questions

- Costs incurred in one interval can be driven by the need in another interval
  - Minimum up/down time constraints
  - Ramp rate constraints etc.
- How can such inter-temporal effects be considered in setting prices?

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Full ELMP provides a promising solution

Example 1 – Full ELMP better treats costs over minimum run time constraints

Unit	EconMin	EconMax	Energy Cost	Start-up	No-load	Min run time	Ramp rate
Wind	0MW	500MW	-$50/MWh	--	--	--	--
Gas	10MW	100MW	$5/MWh	$200	$100/hour	2 hour	20MW/hour

Time	t1	t2	t3
Demand	506	480	400
Wind	496	470	400
Gas	10	10 (min run)	0
LMP	-50	-50	-50
ELMP	8	-50	-50
Full ELMP	14.5	-50	-50

Reflect cost incurred at t2 due to min run time, in a manner as determined by "convex hull" that minimizes uplift

	Cost $	Revenue/Uplift $		
		LMP	ELMP	Full ELMP
Wind	-68,300	-68,300/0	-39,532/0	-36,308/0
Gas	500	-1000/1,500	-420/920	-355/855

Uplift minimized by ELMP includes both uncovered cost and lost opportunity cost (e.g., $15.5/MWh at t1 could better cover cost by $10, but would incur $100 opportunity cost)

ELMP* is inherently multi-interval pricing, associated with challenges in real-time application ⇒

*Note: Full ELMP will be used from now and beyond; results of the current ELMP depend on how close the approximation is

With increased ramping constraints and uncertainty, more questions arise in pricing intertemporal costs

Pricing Needs

- Increasing system ramping needs and new technologies such as storage draw interests of optimization over future intervals
- Real-time dispatch is performed every five minutes on a rolling-window basis
  - Pricing incentives at an advisory interval may disappear when it becomes the binding interval

Research Questions

- How can the pricing incentives be appropriately retained despite changing time interval and/or system conditions?

Ramp Capability Product shows potential

Example 2 – Ramp Product retains stable price signals in multi-interval optimization

Time	t1	t2	t3
Demand	506	540	530
Wind	486	500	500
Gas	20	40	30

LMP	-50	60 (ad.)⇒5	5
ELMP	-50	64 (ad.)⇒6	6

Incentive of pre-ramping at advisory interval t2 disappear when t2 becomes the binding interval

Ramp Requirement		40MW	0	0
Wind MW		480/20	500/0	500/0
Gas MW		26/20	40/0	30/0
LMP $/MWh	Energy	5	5	5
	Ramp	55	0	0
ELMP $/MWh	Energy	9	5	6
	Ramp	59	0	0

Price of Ramp Capability Product provides pre-ramping incentive at t1, despite future changing time and conditions

$	ELMP w/o ramp			ELMP with ramp		
	cost	revenue	uplift	cost	revenue	uplift
Wind	-74,300	-18,300	0	-74,000	11,000	0
Gas	950	-580	1,530	980	1,794	0

Ramp Product can work with both LMP and ELMP; What difference does ELMP make? ⇒

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Anticipating negative energy prices by renewables, conventional units face sustainability challenges

Pricing Needs

- With high penetration of low marginal cost renewables, energy price can be driven near-zero or negative
- Positive-cost fossil plants like gas turbines may need to be held online at their minimum limits to provide reliability services such as ramp product

Research Questions

- Whether and how can these units affect prices, or how can their reliability value be rewarded?
  - *Align market requirement with reliability requirement*
  - *Reflect cost causation to meet the requirement*

ELMP and Ramp Capability Product work together to effectively reflect resource reliability value

Example 3 – ELMP and Ramp Product together price resource reliability value

*(Set Gas Unit EconMin to **30**MW)*

Time	t1	t2	t3
Demand	506/40	540/0	530/0
Wind	476/20	500/0	500/0
Gas	***30***/20	40/0	30/0

Unit provides ramp capability, but is held online at the minimum limit and cannot set prices under LMP

LMP	Energy	-50	5	5
	Ramp	0	0	0
ELMP	Energy	9	5	6
	Ramp	59	0	0

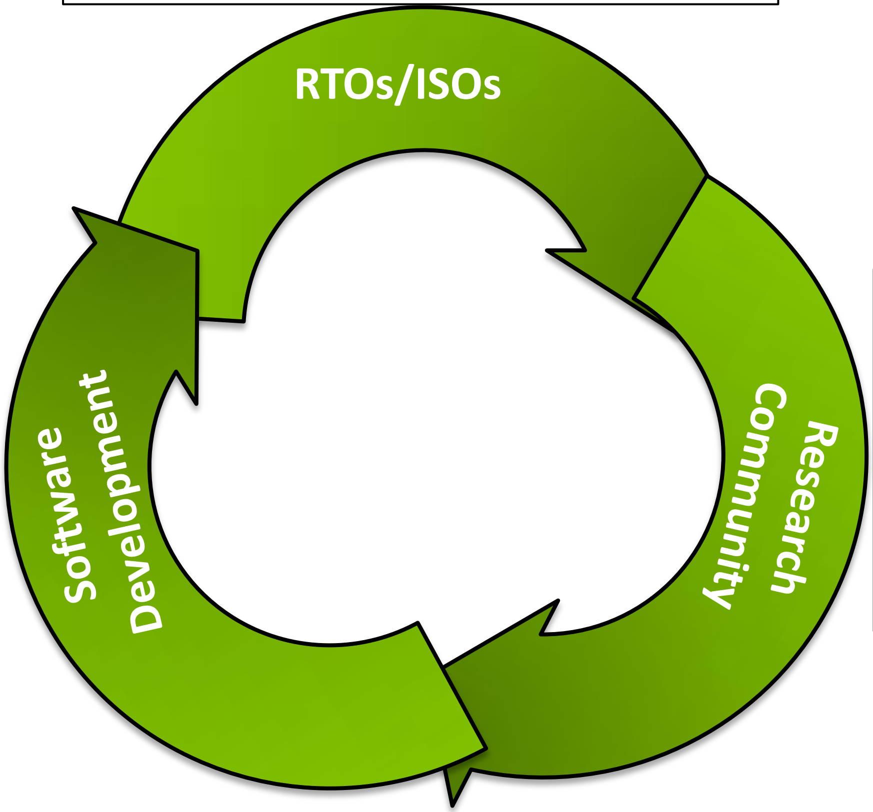
ELMP more effectively reflect the cost causation, including costs associated with commitment to provide reliability service

	Cost	Revenue/Uplift	
		LMP	ELMP
Wind	-73,800	-18,800/0	10,964/0
Gas	1,000	-1,150/2,150	1,830/0

When resources are held at minimum limits to provide ramp flexibility, ELMP can reflect the cost

Computational advancements enable Real-Time and Day-Ahead market enhancements

Business Needs, Market Design ...
Example: P. Gribik, W. Hogan, and S. Pope, "Market Clearing Electricity Prices and Energy Uplift," Dec. 31, 2007



System construction & improvements...
More efficient user interface; Improvement of Market Clearing Engines (GE/IBM solver, parallel computing and HPC)

Theory & Technology advancements ...
B. Hua and R. Baldick "A Convex Primal Formulation for Convex Hull Pricing," IEEE Transactions on Power Systems PP(99), May 2016