Wholesale Electricity Markets and ERCOT

A Quantitative Trading Perspective

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Presentation Outline

Electricity as a Commodity

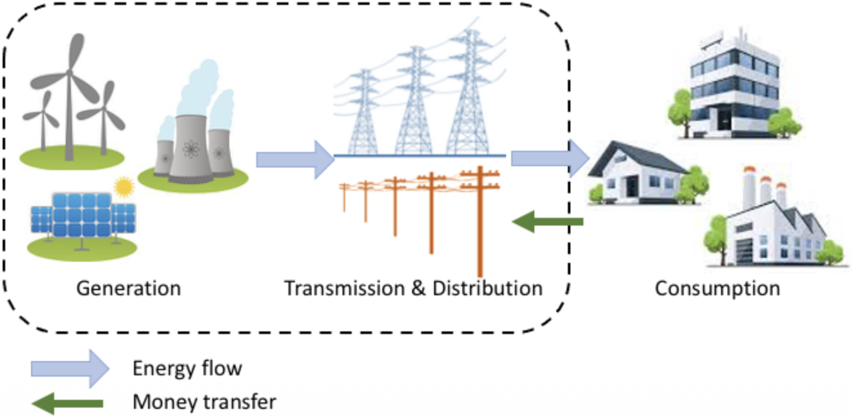
What makes electricity unique?

1. Electricity must be perfectly **balanced between supply and demand** in real time. At every instant, the amount of power generated across the grid must exactly match the amount being consumed by homes, factories, and businesses.
2. **Electricity cannot be stored on a large scale easily**. That means it cannot be stockpiled it for later use; it has to be produced and delivered the very moment it's needed.
3. To keep the system stable, grid operators must **continuously monitor the network and make instant dispatch decisions**, ensuring the flow of electricity stays balanced second by second across thousands of nodes.

Historical Context & ERCOT Formation

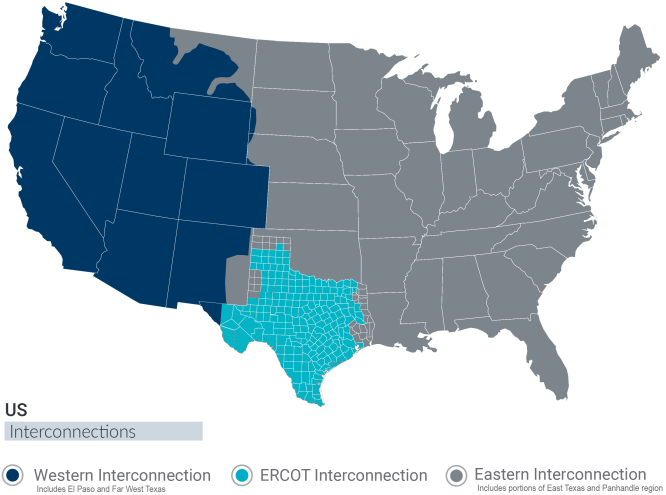
What's the early electricity industry model?

Utilities owned generation, transmission, and distribution. Operated as regional monopolies. Prices set by regulators, not competition. Planning focused on reliability, not market efficiency and innovation.



Historical Context & ERCOT Formation

Where ERCOT operates?



Historical Context & ERCOT Formation

How did Texas deregulate?

1. Texas pursued electricity market deregulation to improve efficiency and promote competition. In 1999, through Senate Bill 7, Texas opened its power market to retail competition within the ERCOT region.
2. This led to the unbundling of vertically integrated utilities into separate entities for generation, transmission, and retail (load-serving). This structural separation was essential to ensure non-discriminatory open access to the transmission network.
3. ERCOT became responsible for maintaining reliability and operating the wholesale and retail electricity markets in Texas. The goal was to increase efficiency, lower costs, and enhance consumer choice.
4. ERCOT is not a for-profit entity, and any positive or negative surplus that is generated by these markets is allocated back to society.

ERCOT Market Architecture

Who participates in electricity market?

1. **Generators** or power producers own power generation assets and typically sell energy and various ancillary services (frequency regulation, spinning reserves, non-spinning reserves) to the system.
2. **Transmission companies** are entities that own parts of the transmission network and follow the instructions of the ISO in operating them.
3. **Load serving entities** / Utilities / Distribution companies procure electricity from the wholesale electricity market and sell it to residential and commercial customers.

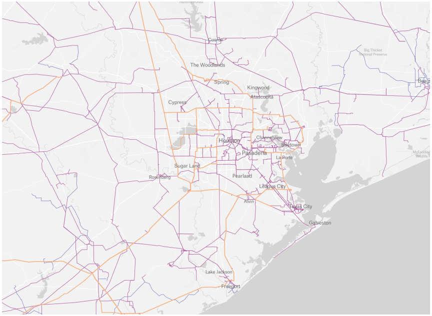
ERCOT Market Architecture

How is energy traded in the wholesale market?

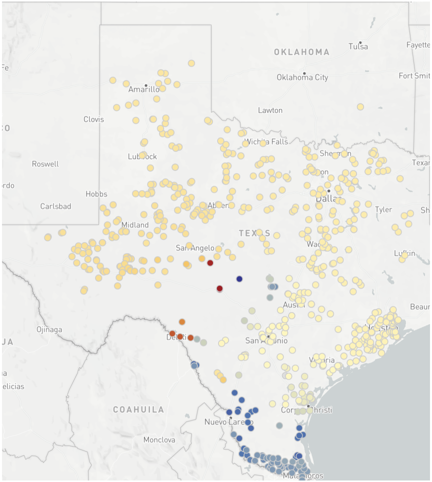
1. The wholesale electricity market trades energy in bulk quantities among producers and Load Serving Entities (LSEs).
2. The fundamental unit of measurement for pricing in this market is $/MWh (dollars per megawatt-hour). This represents the willingness to pay for 1 MW of supply over an hour.
3. Trading energy in bulk requires transportation and a reliable system. Therefore, in addition to energy, the wholesale market also trades transmission services and ancillary services (frequency regulation, spinning reserves, non-spinning reserves) to ensure reliable operation.

ERCOT Market Architecture

What does the power system look like?



Network representation of ERCOT grid around Houston



Example of nodal representation

ERCOT Market Architecture

What are the short term auctions in electricity markets?

1. Power systems must continuously balance supply and demand. Some decisions must be made in advance due to generator constraints (e.g., minimum up/down times, ramp rates).
2. **Day-Ahead Market (DAM)**: Scheduling based on forecast demand and model implemented is SCUC (security constrained unit commitment).
3. **Real-Time Market (RTM)**: Balancing supply and demand as it happens, using available generation and model implemented is SCED (security constrained economic dispatch).

Day-Ahead Market (DAM)

How does DAM work?

1. The ERCOT DAM is a voluntary, forward energy and Ancillary Service market that operates one day prior.
2. The objective of DAM is to enable market participants (generators, LSEs, etc.) to financially hedge against price volatility and manage their generation resources for the following day.
3. The market closes around 10:00 AM one day before the operating day.
4. Once the market closes, the day-ahead SCUC model is run. This does not produce physically binding commitments, but it does produce financially binding commitments.
5. The SCUC model solves for the least-cost combination of energy and Ancillary Services needed to meet the forecasted load for all 24 hours of the next day, while respecting all transmission and security constraints.

Day-Ahead Market (DAM)

How a generator bids hourly in ERCOT DAM?

Hour Ending	Price 1 ($/MWh)	Quantity 1 (MW)	Price 2 ($/MWh)	Quantity 2 (MW)
1	25	100	–	–
2	25	100	–	–
3	25	100	–	–
4	26	150	–	–
5	27	200	–	–
6	28	250	–	–
7	30	300	–	–
8	32	350	–	–
9	35	400	–	–
10	38	450	–	–
11	40	500	60	550
12	42	500	65	550
13	42	500	65	550
14	40	450	60	500
15	38	400	–	–
16	36	350	–	–
17	38	400	–	–
18	40	450	–	–
19	42	500	70	550
20	38	450	–	–
21	34	400	–	–
22	30	300	–	–
23	28	200	–	–
24	25	150	–	–

Example bid curve: for a 1300 MW generator located at PANDA_CT1 node.

Day-Ahead Market (DAM)

What are the key inputs to run SCUC?

1. **Transmission Network Model:** Detailed representation of the ERCOT grid topology and N-1 security constraints.
2. **Planned Transmission and Generation Outages:** Scheduled outages are incorporated to ensure unavailable equipment is excluded.
3. **Energy Bid and Offer Curves:** Submitted by market participants, specifying how much energy they will produce/consume at different prices for a given location and time.
4. **Ancillary Services Offer Curves:** Offers from resources to provide regulation, spinning, and non-spinning reserve services.
5. **Block Bids:** Offers from generators that must run for fixed time blocks due to operational characteristics (e.g., combined-cycle units).
6. **Load Forecasts:** ERCOT's forecast of hourly demand for the next operating day across the system and individual nodes.
7. **Renewable Generation Forecasts:** Expected output from wind and solar units, accounting for variability and uncertainty.

Day-Ahead Market (DAM)

What the SCUC model solves for?

The DAM SCUC is a large-scale, mixed-integer programming problem solved for all 24 hours of the next day. It simultaneously determines the optimal mix of energy and ancillary services.

$$\textbf{Min} \sum_{h=1}^{24} (\text{Commitment Costs}_h + \text{Energy Offer Costs}_h + \text{AS Offer Costs}_h)$$

subject to:

- **Physical Unit Constraints:** Minimum up/down times, startup costs, and ramp rates
- **Energy Balance:** Total dispatched energy must equal the load forecast plus losses.
- **Ancillary Services Requirements**
- **Transmission Constraints:** All transmission limits must hold true under N-1 reliability criterion.

Day-Ahead Market (DAM)

What are the key outputs after the DAM clears?

1. DA Locational Marginal Prices (LMPs) at each node for all hours. It reflects the marginal cost of serving 1 MWh at that node. Decomposition of LMP:
   - **DA Energy component:** System-wide marginal cost of energy.
   - **DA Congestion component:** Cost due to transmission limits.
   - **DA Loss component:** Cost of transmission losses (in ERCOT, losses are assumed in the energy component).
2. Day-Ahead Binding Constraints & Shadow Prices
   - **DA Binding constraints:** Transmission lines or system limits fully utilized in the solution.
   - **DA Shadow price:** Economic value of relaxing a constraint by 1 MW.
3. Scheduled commitment status and generation for each unit per hour.
4. Cleared quantities of ancillary services.
5. Congestion Rent: sum of shadow prices $\times$ flows on binding lines.

Day-Ahead Market (DAM)

Example DA LMPs for Generator Node: PANDA_CT1

Hour	DA Energy Component ($/MWh)	DA Congestion Component ($/MWh)	DA LMP ($/MWh)
1	18	0	18
2	17	-1	16
3	17	0	17
4	18	1	19
5	20	0	20
6	22	-2	20
7	20	-4	16
8	17	-7	10
9	17	-6	11
10	18	-4	14
11	19	-2	17
12	20	0	20
13	21	1	22
14	20	2	22
15	19	0	19
16	18	-3	15
17	18	-5	13
18	22	-4	18
19	21	-2	19
20	22	-1	21
21	20	0	20
22	19	1	20
23	18	0	18
24	17	-1	16

Day-Ahead Market (DAM)

Example DA Binding Constraint: A → B ;;; C → D

Hour	Unconstrained Flow (MW)	Limit (MW)	Shadow Price ($/MWh)
1	50	50	0
2	48	50	0
3	52	50	5
4	55	50	10
5	60	50	15
6	65	50	20
7	70	50	25
8	72	50	27
9	68	50	23
10	65	50	20
11	60	50	15
12	55	50	10
13	52	50	5
14	50	50	0
15	48	50	0
16	45	50	0
17	50	50	0
18	55	50	10
19	60	50	15
20	62	50	17
21	58	50	13
22	52	50	5
23	50	50	0
24	48	50	0

Real-Time Market (RTM)

How does RTM work?

1. ERCOT runs a real-time security constrained economic dispatch (SCED) model every 5 minutes to schedule generation for the next interval, ensuring supply meets demand while respecting transmission and reliability constraints.
2. Decisions in the real-time market are physically binding, unlike the day-ahead market.
3. Generators not committed via bilateral contracts, the day-ahead market, or ancillary services can submit bids to run in real time.
4. The dispatch model calculates locational marginal prices (LMPs) for each node every 5 minutes and issues generation orders accordingly.
5. Real-time dispatch addresses unexpected changes in demand, generator outages, or weather variations that were not anticipated in the day-ahead market.

Real-Time Market (RTM)

What the SCED model optimizes for?

SCED is a mandatory, high-frequency dispatch of already committed resources to instantaneously meet load.

$$\textbf{Min} \sum_{r \in \text{Online}} (\text{Energy Offer Costs}_r)$$

subject to:

- **Power Balance:** Dispatched MW must equal Real-Time Load
- **Dispatch Limits:** Generator output must respect High/Low Dispatch Limits (HDL/LDL), which are defined by their current operating point and their ramp rates.
- **N-1 Security (Transmission):** The dispatch must prevent any monitored transmission element from overloading, both in the base case (current flow) and under all contingency scenarios (N-1 reliability criterion).

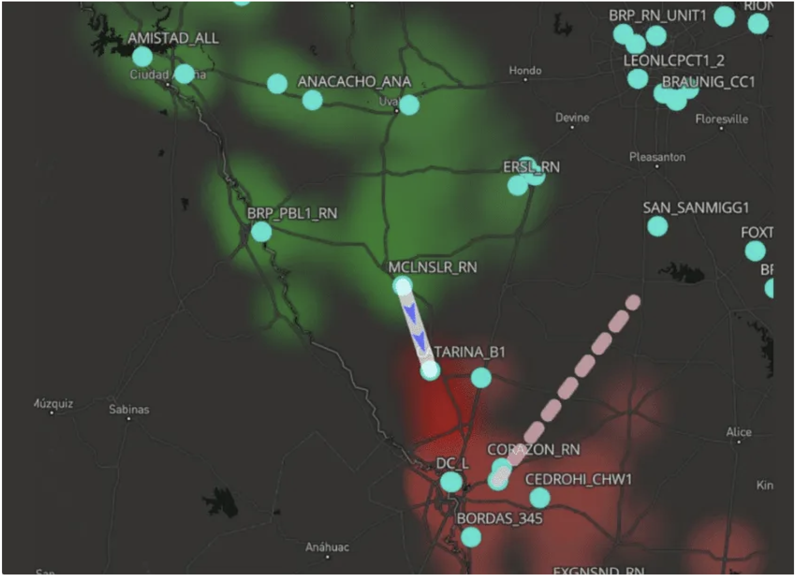
Real-Time Market (RTM)

Key outputs after each 5-min SCED run

1. **RT Base Points (MW):** Generation setpoints sent to generators for the next 5-minute interval.
2. **RT Locational Marginal Prices (LMPs):** Prices ($/MWh) at each node reflecting the marginal cost of supplying the next MW, including energy, congestion, and losses.
3. **RT Binding Constraints and RT Shadow Prices:** Identifies transmission or system limits that are binding; shadow prices indicate how much the total system cost would change if a constraint were relaxed by 1 MW. These values contribute to the congestion component of LMPs.

Real-Time Market (RTM)

Example of a real-time binding constraint



Real-Time Market (RTM)

How do market participants respond to price signals?

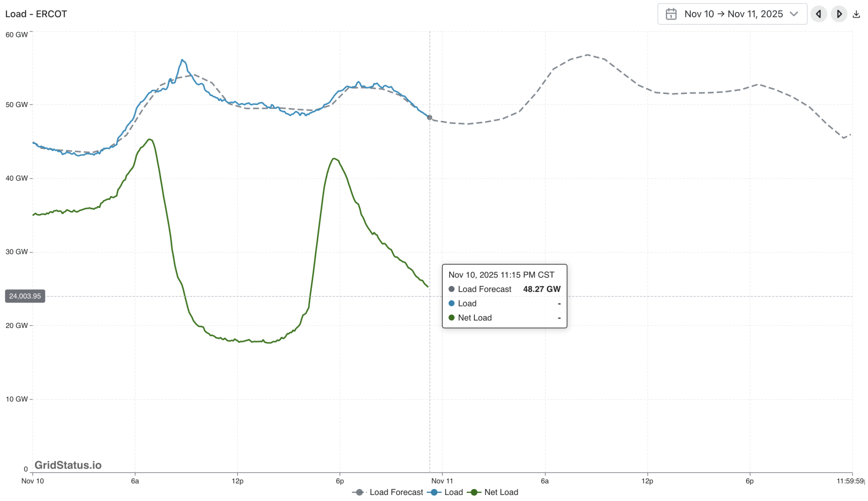
1. When SCED predicts that a post-contingency flow could exceed a transmission limit, it automatically adjusts dispatchable generators to prevent overloads. The resulting Locational Marginal Prices (LMPs) reflect energy, congestion, and losses.
2. Nodes that add flow to the binding constraint typically see lower congestion components.
3. Nodes that relieve the binding constraint typically see higher congestion components.
4. These LMPs provide economic signals: generators adjust output if profitable, and flexible loads respond to low or high prices.
5. On the source side of a binding constraint, flexible consumers—like data centers or Bitcoin miners—may increase consumption to take advantage of low real-time prices.
6. On the sink side, generators not cleared in the Day-Ahead Market may increase production if their variable costs are below the elevated real-time price, earning a profit.

Day-Ahead and Real-Time Markets

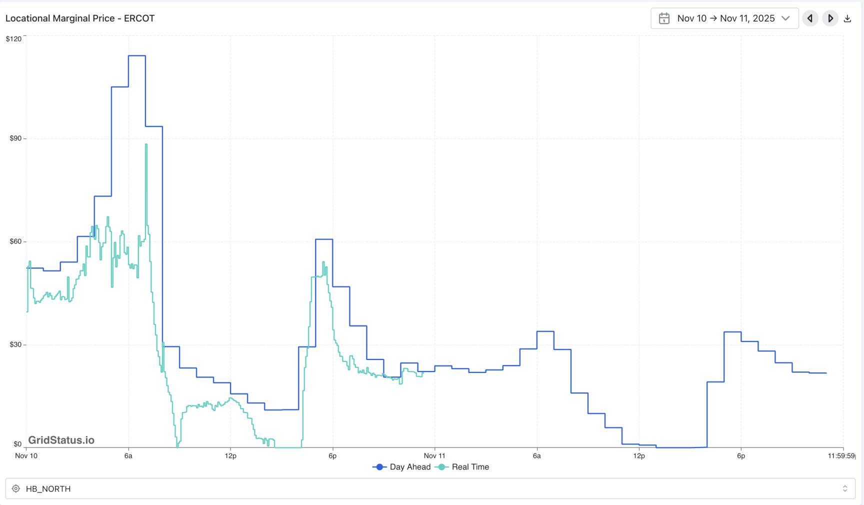
The two-way settlement process

1. Power system operations require continuous balancing of supply and demand.
2. Some decisions are made in advance due to generator operating constraints (e.g., minimum up/down times, ramp rates).
3. Day-Ahead Market (DAM) provides a forward market for electricity trading and Real-Time Market (RTM) balances actual demand.
4. **Two-Way Settlement:**
   - Energy sold in DAM at day-ahead price provides financial certainty.
   - Generators are financially obligated their awarded bids in real time; deviations are settled at real-time price.
   - This structure hedges risk while preserving real-time economic incentives.

Day-Ahead and Real-Time Markets
Load

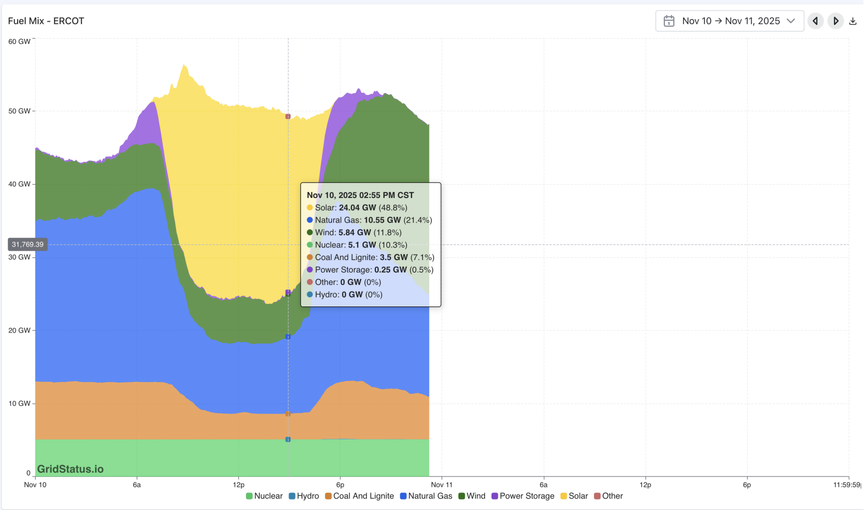


Day-Ahead and Real-Time Markets
HB_NORTH



Day-Ahead and Real-Time Markets

Fuel Mix



Home > Grid and Market Conditions > Energy Storage Resources

Energy Storage Resources

Energy Storage Resources is a graphical representation of energy storage charging and discharging production using real-time data.

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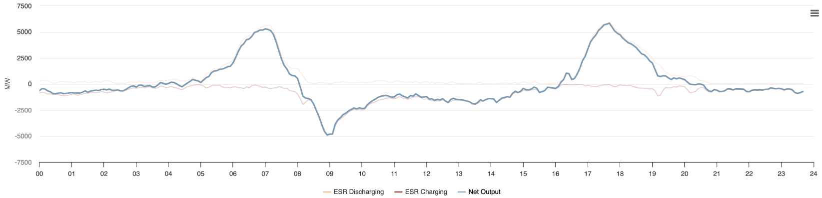

Previous Day | Current Day

Congestion Revenue Rights (CRRs)

Why CRRs?

1. In locational marginal pricing, transmission constraints cause electricity prices to differ between nodes. This means that moving power from a low-priced (source) node to a high-priced (sink) node incurs congestion costs. Market participants face uncertainty in congestion charges when transmitting power across the grid. These charges can fluctuate significantly with system conditions.
2. Transmission constraints complicate market design because the transmission capacity of lines in a scarce resource. In order for market to maximize efficiency, scare resource that are shared between agents should be priced.
3. CRRs allow participants to lock in the financial impact of congestion between two nodes.
4. CRRs may be used as a financial hedge (looking to lock in cost of congestion at the cost of purchasing CRR) or a financial investment (on a speculation that congestion rent is greater than purchase price).

Congestion Revenue Rights (CRRs)

How do CRRs work?

1. CRRs are on a point-to-point basis. Each CRR has a source node and sink node. Source node is the point of injection of power and sink node is the point of withdrawal of power.
2. There are two types of CRR: options and obligations. Options provide a hedge that results only in a payment and obligations provide a hedge that can result in a payment or a charge. The way CRR auction clear, for an option there is always a premium to be paid and they are expensive.
3. In ERCOT, CRR auctions take place twice in a month. One is a monthly auction where market participates to obtain CRRs for next month. Another is annual auction where ERCOT holds long-term auction sequences which cover 6-month strips and extend into future periods beyond the immediate next month upto 3 years ahead.

Congestion Revenue Rights (CRRs)

How are CRRs used in future planning?

1. The results of CRR auctions reveal how market participants perceive future congestion in different parts of the network.
2. For instance, if CRRs associated with delivering power from a generator in West Texas to load centers around Dallas trade at high positive prices, it indicates that market participants expect frequent congestion on those transmission paths. This, in turn, provides an incentive for generation developers to locate new plants closer to the high-priced demand area or in regions where transmission is less constrained, thereby improving overall system efficiency.
3. ERCOT itself can use CRR auction outcomes as a diagnostic tool to understand where the market anticipates bottlenecks. For example, if CRRs between the Houston and South Texas zones consistently exhibit high congestion values, ERCOT may interpret this as evidence of limited transmission capacity in that corridor. This information helps ERCOT prioritize transmission planning and expansion projects to alleviate future congestion and ensure system reliability.

Broader Reflections & Conclusion

What can we learn from ERCOT?

1. Price Signals Drive Action: LMP and the dynamic range of prices (positive and negative) are central to efficiency, serving as the primary tool to align economic decisions (generation/consumption) with physical grid conditions.
2. The Scarcity Problem: The inherent constraints of transmission capacity make it a scarce resource. CRRs are essential for both financially hedging this risk and providing long-term investment signals for network planning.
3. Security is Paramount: The entire market framework (Day-Ahead SCUC, Real-Time SCED, N-1 Criterion) is built around the non-negotiable requirement for instantaneous and secure system balance.
4. Future reliability will increasingly rely on the system's ability to handle variable resources (renewables) and the responsiveness of flexible demand (loads reacting to negative/high LMPs).

Thank You!

Questions?